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Water-Supply and Irrigation Paper No. 115 Series N, Water Power, 10

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

RIVER SURVEYS AND PROFILES MADE DURING 1903

ARRANGED BY

W. CARVEL HALL AND JOHN C. HOYT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

The publications of the United States Geological Survey consists of (1) Annual Reports; (2) Monographs; (3) Professional Papers; (4) Bulletins; (5) Mineral Resources; (6) Water-Supply and Irrigation Papers; (7) Topographic Atlas of the United States, folios and separate sheets thereof; (8) Geologic Atlas of United States, folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports.

The following Water-Supply Papers are out of stock, and can no longer be supplied: Nos. 1-16, 19, 20, 22, 29-34, 36, 39-40, 43, 46, 57-65, 75. Complete lists of papers relating to water supply and allied subjects follow. (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper.)

Series I—Irrigation.

WS 2. Irrigation near Phoenix, Ariz., by A. P. Davis. 1897. 98 pp., 31 pls. and maps.
WS 5. Irrigation practice on the Great Plains, by E. B. Cowgill. 1897. 39 pp., 11 pls.
WS 9. Irrigation near Greeley, Colo., by David Boyd. 1897. 90 pp., 21 pls.
WS 10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker. 1898. 51 pp., 11 pls.
WS 13. Irrigation systems in Texas, by W. F. Hutson. 1898. 68 pp., 10 pls.
WS 17. Irrigation near Bakersfield, Cal., by C. E. Grunsky. 1898. 96 pp., 16 pls.
WS 18. Irrigation near Fresno, Cal., by C. E. Grunsky. 1898. 94 pp., 14 pls.
WS 19. Irrigation near Merced, Cal., by C. E. Grunsky. 1899. 59 pp., 11 pls.
WS 23. Water-right problems of Bighorn Mountains, by Elwood Mead. 1899. 62 pp., 7 pls.
WS 32. Water resources of Porto Rico, by H. M. Wilson. 1899. 48 pp., 17 pls. and maps.
WS 43. Conveyance of water in irrigation canals, flumes, and pipes, by Samuel Fortier. 1901. 86 pp., 15 pls.
WS 70. Geology and water resources of the Patrick and Goshen Hole quadrangles, Wyoming, by G. I. Adams. 1902. 50 pp., 11 pls.
WS 71. Irrigation systems of Texas, by T. U. Taylor. 1902. 137 pp., 9 pls.
WS 74. Water resources of the State of Colorado, by A. L. Fellows. 1902. 151 pp., 14 pls.
WS 87. Irrigation in India (second edition), by H. M. Wilson. 1903. 238 pp., 27 pls.
WS 93. Proceedings of first conference of engineers of the reclamation service, with accompanying papers, compiled by F. H. Newell, chief engineer. 1904. 361 pp.

The following papers also relate especially to irrigation: Irrigation in India, by H. M. Wilson, in Twelfth Annual, Pt. II; two papers on irrigation engineering, by H. M. Wilson, in Thirteenth Annual, Pt. III.

Series J—Water Storage.

WS 33. Storage of water on Gila River, Arizona, by J. B. Lippincott. 1900. 98 pp., 33 pls.
WS 40. The Austin dam, by T. U. Taylor. 1900. 51 pp., 16 pls.
WS 45. Water storage on Cache Creek, California, by A. E. Chandler. 1901. 48 pp., 10 pls.
WS 46. Physical characteristics of Kern River, California, by F. H. Olmsted, and Reconnaissance of Yuba River, California, by Marsden Manson. 1901. 57 pp., 8 pls.
WS 58. Storage of water on Kings River, California, by J. B. Lippincott. 1902. 100 pp., 32 pls.
WS 68. Water storage in Truckee Basin, California-Nevada, by L. H. Taylor. 1902. 90 pp., 8 pls.
WS 73. Water storage on Salt River, Arizona, by A. P. Davis. 1902. 54 pp., 25 pls.
WS 86. Storage reservoirs on Stony Creek, California, by Burt Cole. 1903. 62 pp., 16 pls.
WS 89. Water resources of Salinas Valley, California, by Homer Hamlin. 1904. 91 pp., 12 pls.
WS 93. Proceedings of first conference of engineers of the reclamation service, with accompanying papers, compiled by F. H. Newell, chief engineer. 1904. 361 pp.

The following paper also should be noted under this heading: Reservoirs for irrigation, by J. D. Schuyler, in Eighteenth Annual, Pt. IV.

[Continued on third page of cover.]

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ERRATA.

[Water-Supply Paper No. 115, United States Geological Survey.]

'age 11. Fig. 1 should have had the title "Profile of Catawba River from Marion to Connelly Springs, N. C.," and been placed at page 13.

'age 14. Pl. II should have had the title "Profile of Tallulah River below Blalock, Ga.," and been placed at page 18.

'age 19. Fig. 2 should have had the title "Profile of Tugaloo River below Tallulah Falls, Ga.," and been placed at page 23.

'age 24. Fig. 3 should have had the title "Profile of Savannah River from Andersonville, S. C., to Lisbon, Ga.," and been placed at 29.

'age 30. Pl. III should have had the title "Profile of South and Ocmulgee rivers from Constitution to Macon, Ga.," and been placed at page 46.

'age 47. Fig. 6 should have had the title "Profile of Alcovy River below Dabney's bridge, Georgia," and been placed at page 56.

'age 56. Fig. 8 should have had the title "Profile of upper Chattahoochee River from Nacoochee, Ga., to junction with Chestatee River," and been placed at page 61.

'age 62. Fig. 10 should have had the title "Profile of lower Chattahoochee River from West Point to Columbus, Ga.," and been placed at page 71.

'age 73. Fig. 12 should have had the title "Profile of Chestatee River below Willow, Ga.," and been placed at page 77.

'age 76. Pl. IV should have had the title "Profile of Chippewa River from Reeds Landing, Minnesota, to Flambeau, Wis.," and been placed at page 98.

'age 103. Fig. 18 should have had the title "Profile of Buffalo River from Flatwoods to Lobelville, Tenn.," and been placed at page 11.

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., July 23, 1904.

SIR: I have the honor to transmit herewith a paper entitled "River Surveys and Profiles Made in 1903," which has been arranged by W. Carvel Hall and John C. Hoyt.

This paper contains the results of the cooperative river surveys carried on during 1903 between the topographic and hydrographic branches.

There is a large demand for the data herein presented by engineers and others interested in power development. I therefore recommend that this manuscript be published as a Water-Supply and Irrigation Paper.

Very respectfully, F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

RIVER SURVEYS AND PROFILES OF 1903.

Arranged by W. C. Hall and J. C. Hoyt.

INTRODUCTION.

In order to determine the location of the undeveloped water powers on the various rivers in the United States the United States Geological Survey has from time to time made surveys and profiles of the more important of the rivers on which possible power sites were known to be located. The object of these surveys is to point out localities where power may be developed.

In the determination of the river profiles the general plan of survey adopted was as follows:

The elevations were based upon reliable heights derived from primary or precise levels of the United States Geological Survey. On this datum, with few exceptions, lines of flying levels were carried up the bank of each stream and bench marks were established at intervals of about 1 mile, usually on nails on tree roots. The elevations of the surface of the water at the head and foot of each shoal, rapid, or fall were noted. These levels, with few exceptions, have been tied at both ends. In the case of Broad River primary levels were used instead of flying levels, and regulation bronze tablets left at intervals of 6 miles.

The horizontal control of the survey was by plane table oriented by compass, while the distance was always obtained by means of stadia measurements. To further insure the accuracy of the work, the stadia rod was so divided that one division on it equaled one division of the scale used in plotting.

The field sheets were plotted on the scale of 1 : 22,500, with the exception of the surveys of the Tallulah and Tugaloo rivers, which were on the scale of 1 : 45,000. Several different runs of river were plotted on the same plane-table sheet, the ends of the different sections being so marked that there would be no difficulty in joining them and making one continuous map.

On these sheets were shown the outlines of the river banks, the islands, the positions of rapids, shoals, falls, and existing dams, the

crossings of all ferries and roads, and as much of the culture of the river bottom as could be obtained without leaving the immediate neighborhood of the river. The river banks were contoured carefully and the adjacent river bottoms sketched, all with an interval of 10 feet. On these field sheets are marked in their proper positions the elevations of the various bench marks left, as are also the elevations of the water surfaces wherever obtained.

For each river surveyed, first are given a brief description, a list of the elevations, and a condensed profile of the portion of the river surveyed.

The elevations as given in the original notebooks have been adjusted in accordance with the various primary heights tied to, and the figures herein given are the ones obtained from this adjustment.

On file in the Washington office are the original topographic sheets and profiles on the scale of 1 inch to a mile horizontal and 1 inch to 100 feet vertical.

ACKNOWLEDGMENTS.

In the collection of these data and their preparation for publication special acknowledgment is due to the levelmen and others who carried on the surveys. Acknowledgment is due, also, to Messrs. B. M. Hall and M. R. Hall for suggestions, and to Messrs. C. B. Kendall and D. H. Baldwin, who adjusted the various lines of levels, under the supervision of Mr. S. S. Gannett, geographer.

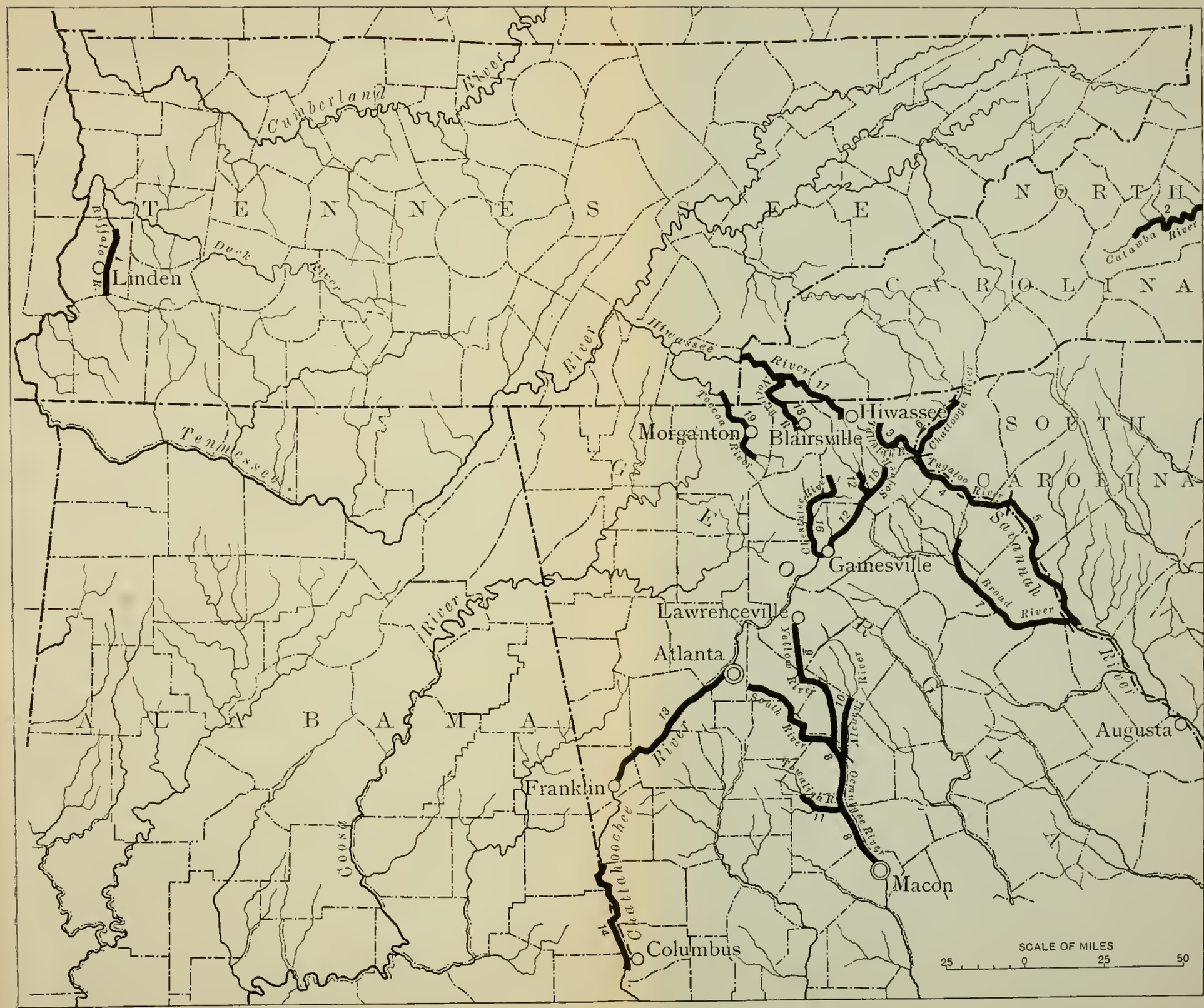
BUFFALO RIVER FROM FLATWOODS TO LOBELVILLE, TENN.

A line of flying levels was run on Buffalo River, Tennessee, from the mouth of Little Opossum Creek, near Flatwoods, to Standing Rock Ford, about 3 miles north of Lobelville—a distance of 47 miles. The plane-table survey was on the scale of 1: 22,500. During the course of the work 28 bench marks on tree roots were marked and 39 water-surface elevations were recorded.

The total fall of that stretch of the river is 109 feet, and is so evenly distributed that there seems to be no power site of any value. There are now two crude dams, one near Linden and the other near Lobelville, supplying power for small gristmills, but at neither place do the conditions warrant the construction of more substantial dams.

The soil near the river is fertile and well adapted to the cultivation of corn, hay, and peanuts.

The elevations in the following list are based upon an assumed elevation of 537.25 feet for the water surface at the mouth of Little Opossum Creek as interpolated from contours sketched on the Mannie sheet. The assumed elevation is probably within 20 feet of correct datum.



MAP SHOWING LOCATION OF SURVEYS IN THE SOUTHERN STATES.

The leveling was done October 4 to 31, 1903, under the direction of Oscar Jones, topographer, by Ralph Hutchins, levelman.

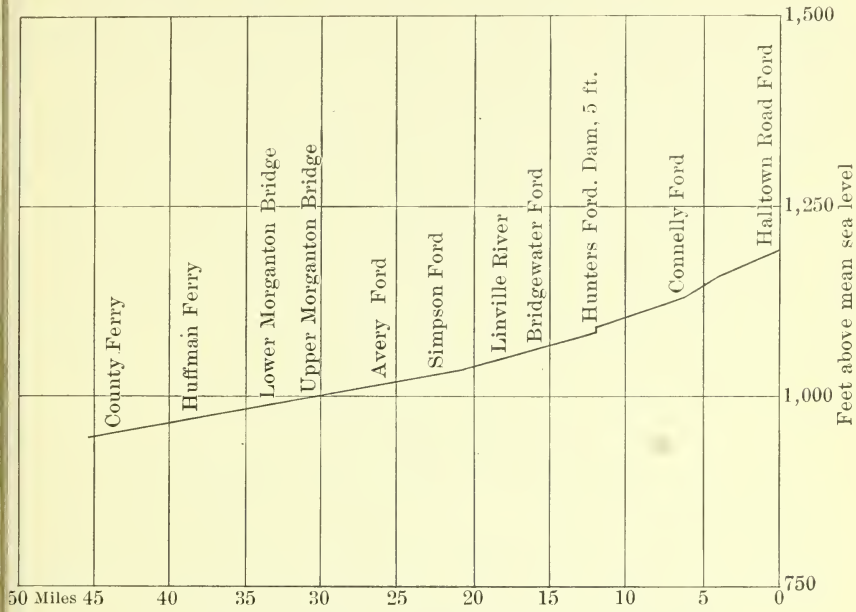


FIG. 1.—Profile of Buffalo River from Flatwoods to Lobelville, Tenn.

Elevations on Buffalo River, Tennessee, from Little Opossum Creek to Standing Rock Ford

Distance in miles.		Elevation in feet.
0.0	Little Opossum Creek, mouth of; east side of river at ford, hackberry tree, nail in root of	537.25
.0	Surface of water	533
3	East side of river at ford, nail in root of elm tree	532.26
.6	Ford, east side of, dead sycamore tree, nail in root of	531.59
1.0	Ford, 125 feet north of; east side of river, nail in root of sycamore tree	532.32
1.2	Surface of water	528
2.1	Ford, south side of river, nail in root of sycamore tree	529.06
2.2	600 feet north of ford, surface of water	525
4.1	Sinking Creek, east side of river, maple tree, nail in root of	524.90
4.1	Sinking Creek, mouth of, surface of water	520
6.3	Ford, 275 feet north of, north bank of river, east side of highway, at angle, nail in root of sycamore tree	521.16
6.2	Ford, 650 feet west of; surface of water	512
8.9	50 feet from river, south side of; sycamore tree, nail in root of	510.01
8.9	Surface of water	503
10.6	Ford, east bank of river, sycamore tree, nail in root of	500.70
10.8	Hurricane Creek, mouth of; surface of water	498
11.9	Hurricane Creek, 1.1 miles from; 50 feet east of ford, nail in root of beech tree	504.17

Elevations on Buffalo River, Tennessee, from Little Opossum Creek to Standing Rock Ford—Continued.

Distance in miles.		Elevation in feet.
11.9	Surface of water	494
13.2	At ford, east bank of river, nail in root of willow tree	489.53
13.2	Surface of water	487
15.2	At ford, south bank of river, nail in root of maple tree	484.23
15.2	Ford, 800 feet west of; surface of water	482
15.5	Ford, south bank of river, nail in root of sycamore tree	485.15
16.6	Ford, east bank of river, nail in root of sycamore tree	482.29
16.8	County bridge, west abutment, bolt in base of girder	499.45
17.3	Ford, east bank of, nail in root of sycamore tree	483.03
17.3	Surface of water	477
19.9	Coon Creek Ford, east bank of river, nail in base of willow tree	476.42
19.9	Ford, 350 feet north of, surface of water	471
21.3	Ford, 106 feet west of; west bank of river, nail in base of willow tree	470.04
21.3	Ford, surface of water	467
22.3	Ford, east bank of river, screw in base of sycamore tree	469.70
22.3	Ford, surface of water	465
22.6	Brush creek, east bank of river, nail in root of sycamore tree	467.29
22.6	Surface of water	465
23.7	Above dam, surface of water	464
23.7	Below dam, surface of water	459
24.2	Ford, west bank of river, top of large rock	459.32
24.2	Ford, 600 feet below, surface of water	457
26.1	Ford, west bank of river, top of large rock	454.16
26.1	Surface of water	452
26.6	Beardstown, east bank of river, at ford, nail in root of sycamore tree	454.24
26.6	650 feet below ford, surface of water	451
28.1	Ford, west bank of river, nail in root of sycamore tree	452.90
29.7	Ford, east bank of river, nail in root of hackberry tree	449.51
30.3	Ford, south bank of river, road, south side, nail in root of sycamore tree	445.47
30.3	Ford, 650 feet below, surface of water	441
31.9	Above dam, surface of water	441
31.9	Below dam, surface of water	435
31.9	Ford, south bank of river, road, west side, nail in root of sycamore tree	438.32
34.3	Ford, east bank of river, nail in base of sycamore sapling	434.02
34.3	Surface of water	431
35.4	Dodson Ford, east bank, top of rock	430.51
36.4	Hester Ford, surface of water	426.59
40.9	Logan Ford, south bank, west side of road, nail in base of willow tree	419.08
41.2	Standing Rock Ford, south bank, nail in root of maple tree	420.61

CATAWBA RIVER FROM MARION, N. C., TO CONNELLY SPRINGS, N. C.

Catawba River was surveyed from the Halltown road crossing, near Marion, N. C., down the river to the mouth of Johnsons Mill Creek, near Connelly Springs, N. C.—a distance of 45 miles. A line of flying levels was run in connection with the plane-table stadia traverse, which was on the scale of 1:22,500, based on a permanent bench mark of the United States Geological Survey at Marion, N. C. This flying line is connected with a precise line along the Southern Railway, run by the Geological Survey in 1896, at Bridgewater, Glen Alpine, Morganton, and Connelly Springs, at each of which points there is a permanent bench mark. There were only three temporary bench marks set along the river, but there were 160 water-surface elevations recorded, all of which were adjusted to the mean reading on the gage established at the upper bridge near Morganton. The work was done in July, August, and September, 1903, by R. C. Howard and S. A. Obenshain, under the direction of W. C. Hall, topographer.

In the stretch of river surveyed there is a total fall of 243 feet. At present there is only one crude dam—at John River Road Ford, where there is a fall of 4 feet, supplying power to operate Hunter's gristmill. There is a dam site near Connelly Ford. The combined fall of two shoals about half a mile apart is 12.3 feet and a long, rocky island in the lower part of the shoal would somewhat facilitate the construction of a dam. At this point the river is about 200 feet wide, with rocky cliffs on both banks. The river bottom is very fertile, the principal crops being corn and hay.

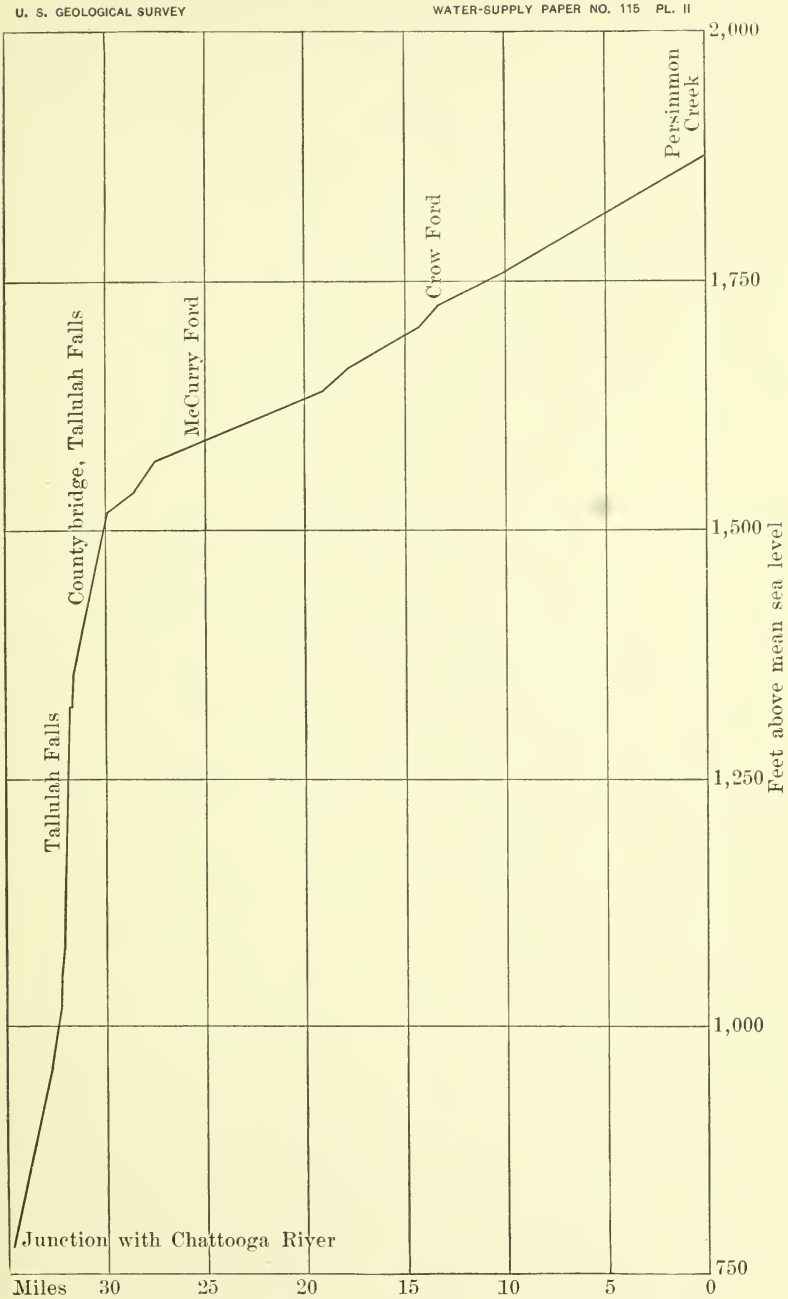
Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.

Distance in miles.		Elevation in feet
0.0	Halltown Road Ford, head of island, head of shoals, surface of water	[a]1,189
.1	Foot of shoals, surface of water	1,187
.2	Head of shoals, surface of water	1,187
.2	Foot of shoals, surface of water	1,184
.5	Head of shoals, surface of water	1,184
.7	Foot of shoals, surface of water	1,179
1.1	Mouth of North Fork, 0.5 mile above, head of shoals, surface of water	1,179
1.1	Foot of shoals, surface of water	1,177
1.3	Head of shoals, surface of water	1,177
1.3	Foot of shoals, surface of water	1,175
1.7	Head of shoals, surface of water	1,174
1.8	Foot of shoals, surface of water	1,172
2.1	Head of shoals, surface of water	1,170
2.3	Foot of shoals, surface of water	1,167

[a] Adjusted to bench mark at Marion; McDowell County court-house; west face, at south end of portico, bronze tablet marked "1438"; elevation, 1,436.857 feet.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
2.4	Head of shoals, surface of water	1,166
3.2	Foot of shoals, surface of water	1,157
3.4	Head of shoals, surface of water	1,156
3.4	Foot of shoals, surface of water	1,154
4	Head of shoals, surface of water	1,153
4.2	North bank of island, foot of shoals, surface of water	1,146
4.4	Head of island, head of shoals, surface of water	1,146
4.4	Foot of island, foot of shoals, surface of water	1,141
4.7	Head of shoals, surface of water	1,140
4.7	Foot of shoals, surface of water	1,137
4.8	Head of shoals, surface of water	1,137
4.8	Foot of shoals, surface of water	1,134
5.1	Head of shoals, surface of water	1,134
5.1	Foot of shoals, surface of water	1,133
5.3	Head of shoals, surface of water	1,133
5.3	Foot of shoals, surface of water	1,131
5.4	Head of shoals, surface of water	1,131
5.4	Foot of shoals, surface of water	1,130
5.7	Connelly Ford, head of shoals, surface of water	1,130
5.8	Foot of shoals, surface of water	1,127
6	Head of shoals, surface of water	1,126
6	Foot of shoals, surface of water	1,126
6.1	Head of shoals, surface of water	1,125
6.1	Small island in shoals, foot of shoals, surface of water	1,124
6.6	Between large islands, head of shoals, surface of water	1,124
6.7	Foot of islands, foot of shoals, surface of water	1,122
6.9	At head of broad flood channel, head of shoals, surface of water	1,122
7	Foot of shoals, surface of water	1,119
7.3	At foot of broad channel, head of shoals, surface of water	1,119
7.3	Foot of shoals, surface of water	1,116
7.5	Head of shoals, surface of water	1,116
7.5	Foot of shoals, surface of water	1,115
7.8	Head of shoals, surface of water	1,115
7.8	Foot of shoals, surface of water	1,114
8.2	Head of shoals, surface of water	1,113
8.5	Foot of shoals, surface of water	1,108
8.5	Head of shoals, surface of water	1,108
8.7	Foot of shoals, surface of water	1,105
9.2	John River Road, head of shoals, surface of water	1,103
9.2	Foot of shoals, surface of water	1,102
9.8	Just below ford, head of shoals, surface of water	1,101
9.8	Foot of shoals, surface of water	1,099



PROFILE OF CATAWBA RIVER FROM MARION TO CONNELLY SPRINGS, N. C.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
10	Head of island, head of shoals, surface of water	1,099
10.2	Foot of shoals, surface of water	1,094
10.8	Head of shoals at head of island, surface of water	1,094
10.9	Foot of island, foot of shoals, surface of water	1,092
11.1	Head of shoals, surface of water	1,092
11.1	Foot of shoals, surface of water	1,089
11.6	Just above dam, surface of water	1,089
11.6	Below ford, foot of shoals, surface of water	1,084
12	Head of shoals, surface of water	1,083
12	Foot of shoals, surface of water	1,079
12.4	Head of shoals, surface of water	1,079
12.4	Foot of shoals, surface of water	1,079
13	Head of shoals, surface of water	1,078
13.1	Foot of shoals, surface of water	1,075
13.3	Head of shoals, surface of water	1,075
13.3	Foot of shoals, surface of water	1,074
13.5	Below head of island, head of shoals, surface of water	1,074
13.7	Foot of two islands, foot of shoals, surface of water	1,070
13.9	Head of shoals, surface of water	1,070
13.9	Foot of shoals, surface of water	1,070
14.4	Head of shoals, surface of water	1,069
14.4	Foot of shoals, surface of water	1,069
14.5	Bridgewater, in front of station, top of north rail	[a]1,095.7
14.5	Head of shoals, surface of water	1,068
14.6	Foot of shoals, surface of water	1,068
15	Head of shoals, surface of water	1,067
15	Foot of shoals, surface of water	1,066
15.1	Just above head of shoals, surface of water	1,066
15.2	Head of shoals, surface of water	1,065
15.2	Foot of shoals, surface of water	1,062
15.4	Head of shoals, surface of water	1,062
15.5	Foot of shoals, surface of water	1,062
15.8	Head of shoals, surface of water	1,061
15.9	Foot of shoals, surface of water	1,061
16.4	Head of shoals, surface of water	1,058
16.8	Foot of shoals, surface of water	1,056
17	Head of shoals, surface of water	1,054
17.2	Foot of shoals, surface of water	1,054
18	Just above head of upper island, head of shoals, surface of water	1,051
18.1	Between island and south bank of river, foot of shoals, surface of water	1,049

[a] Bridgewater, 0.4 mile east of; bridge seat at west end of Muddy Creek Bridge, 2.75 feet south of south rail, copper bolt marked "U. S. G. S., 1091;" elevation, 1,089.549 feet.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
18.2	Mouth of Linville River, below ford, at head of island and south bank, head of shoals, surface of water	1,048
18.4	Between island and south bank, foot of shoals, surface of water	1,046
18.7	Head of small island, head of shoals, surface of water	1,045
18.7	Center of island, foot of shoals, surface of water	1,045
18.9	Head of two small islands, head of shoals, surface of water	1,045
19.1	Foot of shoals, surface of water	1,040
19.6	Long narrow island along north bank, head of short shoal, surface of water	1,039
19.8	Head of shoals, surface of water	1,038
19.8	Foot of shoals, surface of water	1,037
20.1	Above ford, head of shoals, surface of water	1,036
20.3	Head of shoals, surface of water	1,035
20.4	Foot of shoals, surface of water	1,033
20.9	Head of shoals, surface of water	1,032
20.9	Foot of shoals, surface of water	1,031
21.3	Head of shoals, surface of water	1,031
21.3	Foot of shoals, surface of water	1,030
21.5	Head of shoals, surface of water	1,030
21.7	Head of large island, head of shoals, surface of water	1,030
22	250 feet below foot of large island, foot of shoals, surface of water	1,026
22.4	Ford, head of shoals, surface of water	1,026
22.5	Foot of shoals, surface of water	1,025
23.4	Head of shoals, surface of water	1,024
23.7	Head of shoals, surface of water	1,023
23.7	Foot of shoals, surface of water	1,022
24	Head of shoals, surface of water	1,022
24.3	Foot of shoals, surface of water	1,016
25	Avery Ford, 50 feet above, head of shoals, surface of water	[a] 1,015
25	Foot of shoals, surface of water	1,013
25.4	Head of shoals, surface of water	1,013
25.4	Foot of shoals, surface of water	1,012
26.6	Between long island and north bank of river, head of shoals, surface of water	1,009
26.6	Foot of shoals, surface of water	1,007
27.2	Surface of water	1,006
28.1	Head of shoals, surface of water	1,004
28.2	Head of long narrow island, foot of shoals, surface of water	1,003
29	Greenlea Ford, head of shoals, surface of water	1,001
29.1	Foot of shoals, surface of water	1,001

[a] Circuit from White Ford to Avery Ford is adjusted to Glen Alpine, 73.2 feet north of north rail of main track, southeast corner of brick basement of Hennessee & Co.'s store, bronze tablet marked "1215;" elevation, 1,213.944 feet.

Elevations on Catawba River between Halltown Road and Connelly Springs, N. C.—Cont'd.

Distance in miles.		Elevation in feet.
29.4	Between island and mouth, head of shoals, surface of water	1,000
29.6	Foot of island, foot of shoals	998
29.9	Head of shoals, surface of water	998
29.9	Foot of shoals, surface of water	997
30.2	Upper Morganton Bridge, head of shoals under, surface of water	[a] 996
31.7	Fleming Ford, head of islands at, head of shoals, surface of water	992
32	Foot of shoals, surface of water	988
33	Lower Morganton Bridge, under, surface of water	986
33.5	Head of shoals, surface of water	986
34.2	Foot of shoals, surface of water	977
34.4	Head of shoals, surface of water	976
34.8	Below island at mouth of creek on south bank, foot of shoals, surface of water	974
35.5	Mouth of John River, surface of water	972
37.1	Head of shoals, surface of water	969
37.9	Foot of shoals, surface of water	963
38.5	Huffman Ferry, north bank, west side of road, nail in post	974.2
	Huffman Ferry, at east corner of Huffman's house, nail in root of tree at	1,011.75
38.5	Surface of water	961
38.7	Head of shoals, surface of water	959
40.7	At mouth of creek on south, head of shoals, surface of water	957
40.7	Foot of shoals, surface of water	956
41.2	Head of large island, head of shoals, surface of water	955
41.2	Between island and north bank of river, foot of shoals, surface of water	955
41.4	Foot of island, head of shoals, surface of water	955
41.4	Foot of shoals, surface of water	955
41.6	Lovelady Ford, at head of small island between large island and south bank, head of shoals, surface of water	954
41.8	Lovelady Ford, north bank of river, surface of water	953
41.9	Foot of large island at foot of shoals, surface of water	951
43.6	County Ferry, 200 feet south of; west side of road, nail in box alder	968.8
43.6	Surface of water	948
43.8	Head of shoals, surface of water	947
43.8	Foot of shoals, surface of water	947
44.5	Head of shoals, surface of water	947
44.5	Foot of shoals, surface of water	[b] 946

[a] Upper Morganton Bridge line adjusted to Morganton, Burke County court-house, extreme northwest corner of north portico, bronze tablet marked "1182;" elevation, 1,180.774 feet.

[b] Connelly Springs, 142.4 feet north of north rail of main track, James Hudson's brick store, south front, near east corner, bronze tablet marked "1193;" elevation, 1,191.762 feet.

Johnson Mill Creek flows into Catawba 1.6 miles below County Ferry, south side of river.

NOTE.—Water-surface elevations adjusted to mean gage reading 1.8 feet at Upper Morganton Bridge Elevation of 1.8-footmark, 996.3 feet.

TALLULAH RIVER BELOW BLALOCK, GA.

Tallulah River rises in Habersham and Rabun counties, Ga., flows in a southeasterly direction, and joins Chattooga River a little below Tallulah Falls, thus forming Tugaloo River. During August, 1903, this river was surveyed between Tallulah Falls, Ga., and the mouth of Persimmon Creek, near Blalock, Ga. The distance between these points is about 33 miles, and there is a fall of 451 feet. The survey consisted of a line of primary levels based upon the United States Geological Survey bench mark at Tallulah Falls, and a plane-table survey of the course of the river. The field sheets were plotted on a scale of 1:22,500, 30 bench marks were established, and 69 water-surface elevations obtained.

Tallulah River is a typical mountain stream and is subject to sudden freshets. As the Chattooga is of the same character the Tugaloo is a dangerous stream, a rise of 1.6 feet per hour for three consecutive hours being recorded on March 23, 1903, at the Southern Railway bridge near Toccoa, Ga. On this occasion the river rose 15.2 feet in eighteen hours.

Tallulah River crosses the fall line at Tallulah Falls, Ga. In this vicinity is some of the most picturesque and rugged scenery in the Southern States. In 3 miles the river drops from 1,415 to 755 feet above sea level, or a distance of 660 feet. The principal falls, in the order in which they occur, are L'eau D'or, 28 feet; Tempesta, 76 feet; Hurricane, 89 feet; Oceana, 41 feet; Bridal Veil, 17 feet—all in a distance less than three-fourths of a mile. On either bank are precipitous cliffs, rising in some places 500 feet sheer. The gorge continues to the Tugaloo, with the exception of one place about one-half mile long, where it opens up and forms what is known as the Old Valley farm. On either side the country is covered with woods, but not a great deal of merchantable timber appears to be available.

In 2 miles, above Tallulah Falls, the river has a fall of 110 feet. At the head of this fall the bottom widens into a valley which appears to be an excellent basin for storing water. Three and one-fourth miles farther upstream at an unnamed shoal with a 12-foot fall, there is a fair site for a dam. The bottom is rocky, and there are steep hills on either side.

Five miles farther upstream is a shoal with a 25-foot fall, steep hills on either side, and hard rock bottom. Just above Denton Ford is a 23-foot shoal about three-fourths of a mile long where there is a splendid site for a dam.

The fall in the lower Tallulah below the falls is about 250 feet. A large portion of this fall can be used for power without interfering with the resort at Tallulah Falls. By installing an electrical plant at the upper end of Old Valley farm a good power could be obtained.

The elevations in the following list are based upon the elevation of a bronze tablet in rock 70 feet east of the public road and 20 feet south of Tallulah Falls, station marked "1569 Atlanta." This elevation is accepted as 1,568.302 feet above mean sea level in accord with the 1903 adjustment of the precise-level net. The line is corrected to accord with primary work at mouth of river and at Burton.

The leveling was done in 1903, under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

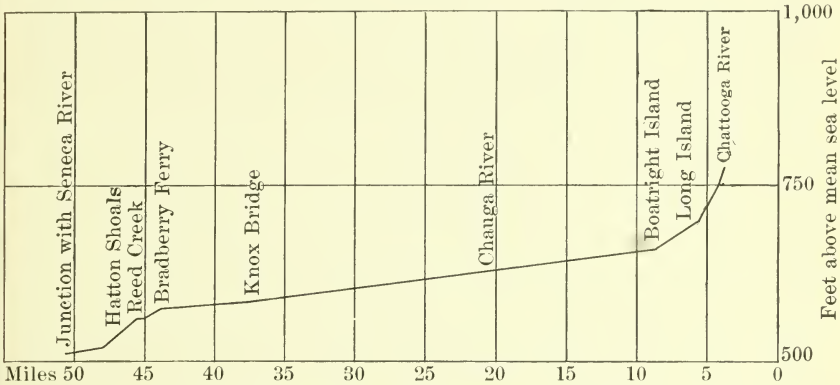


FIG. 2.—Profile of Tallulah River below Blalock, Ga.

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.

Distance.		Elevation in feet
0.0	Junction of Chattooga and Tallulah rivers, surface of water	754
.0	100 feet north of junction rivers, edge of river, point on rock	761.29
.0	200 feet north of junction rivers, west side of Tugaloo River, gum tree, nail in root of	762.65
.2	Chattooga River, 500 feet north of, west side of Tallulah River, nail in root of oak stump	769.46
.3	Surface of water	767
.4	Mouth of small stream, surface of water	782
.6	150 feet west of river	799.86
.9	Surface of water	818
1.3	Surface of water	848
1.6	Surface of water	878
1.7	Surface of water	893
1.8	Surface of water	911
2	Foot of rapids, surface of water	935
2.1	Middle of rapids, surface of water	944
2.2	Head of rapids, surface of water	947
2.2	Foot of rapids, surface of water	954
2.25	Surface of water	964

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd.

Distance in miles.		Elevation in feet.
2.3	Foot of small falls, surface of water	981
2.35	Foot of rapids, surface of water	987
2.38	300 feet below bend, head of rapids, surface of water	980
2.4	Surface of water	997
2.5	Surface of water	1,008
2.6	Bridal Veil Falls, foot of, surface of water	1,022
2.6	Head of falls, surface of water	1,039
2.65	Surface of water	1,057
2.8	Oceana Falls, foot of, surface of water	1,074
2.85	Head of falls, surface of water	1,115
3.1	Hurricane Falls, foot of, surface of water	1,140
3.1	Head of Hurricane Falls, surface of water	1,229
	Tempesta Falls, foot of, surface of water	1,246
3.1	Tempesta Falls, head of, surface of water	1,322
3.2	L'eau d'or Falls, foot of, surface of water	1,322
3.2	L'eau d'or Falls, head of, surface of water	1,350
3.3	Surface of water	1,379
3.4	Surface of water	1,396
3.6	Clayton Road iron highway bridge, surface of water	1,414
	Tallulah Falls station, 70 feet east of public road, 20 feet south of station, in rock, bronze tablet marked "1569 Atlanta"	1,568.302
3.6	Tallulah Falls, 0.5 mile northeast of; at forks of road, 50 feet south of bridge over river	1,457.92
3.6	Clayton Road iron highway bridge, 0.5 mile north of Tallulah Falls, floor of	1,441.87
	Surface of water	1,419
	Opposite stone pier railroad bridge, surface of water	1,439
	Surface of water	1,449
	On rock, surface of water	1,459
4.9	Foot of falls, surface of water	1,486
4.9	Top of falls, surface of water	1,492
5.1	Surface of water	1,509
5.5	Head of island, surface of water	1,530
5.6	20 feet west of Tallulah Falls Railroad, point on top of rock	1,538.21
5.6	Surface of water	1,529
6	Surface of water	1,538
6.5	Surface of water	1,553
6.6	Surface of water	1,559
7.3	150 feet east of river, in cornfield, dead apple tree, nail in root of	1,579.23
7.3	Surface of water	1,569
8.4	Surface of water	1,573

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd.

Distance in miles.		Elevation in feet.
8.6	Surface of water	1,578
8.7	65 feet north of river, in cornfield, walnut tree, nail in root of	1,589.25
8.7	Surface of water	1,578
9.6	Tiger Creek, on point of land between river and creek, burnt poplar tree, nail in side of	1,590.30
9.6	Surface of water	1,584
9.9	Surface of water	1,589
10	5 feet west of river, in footpath, point on sharp rock	1,595.59
10.2	Surface of water	1,592
10.4	Surface of water	1,596
10.5	10 feet west of river, nail in root of beech tree	1,601.32
10.6	Surface of water	1,600
10.9	Surface of water	1,603
11.8	Crane Ford, 150 feet west of, apple tree, nail in root of	1,620.33
11.8	Surface of water	1,607
12.1	Surface of water	1,610
13.3	Dockens Ford, 12 feet west of river, nail in side of dead tree	1,623.06
13.3	Surface of water	1,615
13.8	Ellord Ford, 150 feet east of, at bend of, poplar tree, nail in side of	1,634.36
13.8	Surface of water	1,621
14.4	Surface of water	1,626
14.5	Surface of water	1,628
14.6	Eden Church, 150 feet west of, 150 feet east of river, nail in root of large red-oak tree	1,649.41
15.6	Taylor Shoals, 10 feet west of river, middle of, point on large flat rock	1,644.90
15.6	Surface of water	1,641
16.2	Surface of water	1,648
16.5	Surface of water	1,657
16.6	Surface of water	1,657
17.7	James Smith boat landing, 2 feet west of river, nail in stump	1,670.53
18.4	Fall Creek, mouth of, surface of water	1,669
18.6	Jones Ford, 6 feet south of river, slanting persimmon tree, nail in side of	1,677.33
18.6	Surface of water	1,674.6
19.2	Flat Creek, mouth of, surface of water	1,681
20.6	Surface of water	1,687
20.9	Cliff Creek, mouth of, surface of water	1,690
21.4	Surface of water	1,697
21.5	Denton Ford, 10 feet west of river, nail in root of pine tree	1,703.61
21.5	Surface of water	1,701
21.8	Mouth of small stream, surface of water	1,703
21.9	Seal Creek, mouth of, foot of double shoals, surface of water	1,704

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd.

Distance in miles.		Elevation in feet.
22	Surface of water	1,707
22.3	Middle of shoals, surface of water	1,714
22.6	Crow Ford, 100 feet south of, 10 feet south of river, twin hemlock tree, nail in root of	1,725.93
22.6	Surface of water	1,724
22.7	Scarecrow Creek, mouth of, surface of water	1,727
24	George Creek, mouth of, surface of water	1,737
24.5	Bridge Creek, mouth of, surface of water	1,738
25	In shoals, surface of water	1,747
25.1	—— Ford, surface of water	1,749
25.1	At above ford, south edge of river, point on rock	1,750.29
25.6	Rocky Ford, 10 feet south of, dead hemlock tree, nail in root of	1,758.47
25.6	Surface of water	1,756
25.9	Surface of water	1,757
26.2	Kenny Creek, mouth of, surface of water	1,760
26.3	Fuller Ford, surface of water	1,760
26.4	Fuller Ford, 500 feet northwest of, point on rock	1,762.62
27	Surface of water	1,767
27.3	Cannon Ford, 75 feet southwest of, nail in root of white oak	1,781.97
27.3	Surface of water	1,769
28.2	—— Ford, west side of, nail in root of red gum tree	1,777.87
28.2	Surface of water	1,774
28.5	Wildcat Creek, 50 feet southwest of, west side of road, point on rock	1,783.19
28.5	Surface of water	1,776
29.3	Surface of water	1,785
29.5	Surface of water	1,787
29.6	Dicks Creek, surface of water	1,789
30.1	Burton, 12 feet southwest of bridge, nail in root of maple tree	1,794.96
30.1	Floor of bridge	1,806.4
30.1	Surface of water	1,790
30.1	High-water mark	1,804
30.2	Burton, 1,000 feet above bridge, 15 feet east of river, 10 feet west of road, bronze tablet marked "——"	1,795.140
32.1	12 feet west of ford, nail in side of ash tree	1,819.04
32.1	Surface of water	1,813
32.4	Surface of water	1,819
32.7	Murford, 100 feet southwest of, nail in west side of white-oak tree	1,838.05
32.7	Surface of water	1,824
33	Rocky Ford, surface of water	1,829
33.1	Shallow Ford, 500 feet southeast of, in road, point on rock	1,841.48
33.2	Surface of water	1,835.

Elevations on Tallulah River from mouth, near Tallulah Falls, to near Blalock, Ga.—Cont'd.

Distance in miles.		Elevation in feet.
33.6	Deep Ford, 30 feet south of, nail in side of sycamore tree	1,842.39
33.6	Surface of water	1,839
34.3	Popcorn Creek, mouth of, surface of water	1,849
35	Deep Ford, 3 feet east of, nail in side of beech tree	1,862.03
35.8	Persimmon Creek, 75 feet east of river, 30 feet south of creek, nail in side of hickory tree	1,881.67

TUGALOO RIVER BELOW TALLULAH FALLS, GA.

Tugaloo River, which flows in a southeasterly direction between Georgia and South Carolina, is a continuation of Savannah River, and extends from the mouth of Seneca River to the mouth of Chattooga River. The bed of the stream is in Georgia. The survey of this river covered a distance of 50½ miles. It connected with the survey of Savannah River at Andersonville, and extended past the mouth of the Chattooga along the Tallulah as far as Tallulah Falls. The primary levels were based upon the United States Geological Survey bench mark at Parkesville, Ga. Nine bench-mark tablets and 64 temporary bench marks were established, and 98 water-surface elevations were obtained. The plane-table sheets were plotted on a scale of 1:22,500 for that portion of the survey above the mouth of the Chattooga; from that point to Owens Shoals the scale was 1:45,000; between Owens Shoals and Andersonville it was 1:22,500.

From the head of the Tugaloo to a point about one mile above the mouth of Panther Creek the banks are very steep, but are not so marked as along the Tallulah, except in some places where there is a cliff on one side. Below the point above mentioned the bottom is from one-fourth to three-fourths mile wide in most places, the soil being very fertile and in a high state of cultivation. Cotton is the main crop, with corn next, wheat, rye, sugar cane, etc., combined making but a small percentage of the yield. The timber is very scattered.

The elevations in the following list are based on an aluminum tablet marked "1050 M. C." at Washington street entrance to the State capitol at Atlanta, the elevation of which is now accepted as 1,049.546 feet above mean sea level. The initial point upon which these levels depend is a bronze tablet at north side of east entrance at court-house at Clarksville, Ga., marked "1373 Atlanta," the elevation of which is accepted as 1,371.991 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903 under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

All permanent bench marks are marked with the letters "Atlanta" in addition to the figures of elevation.

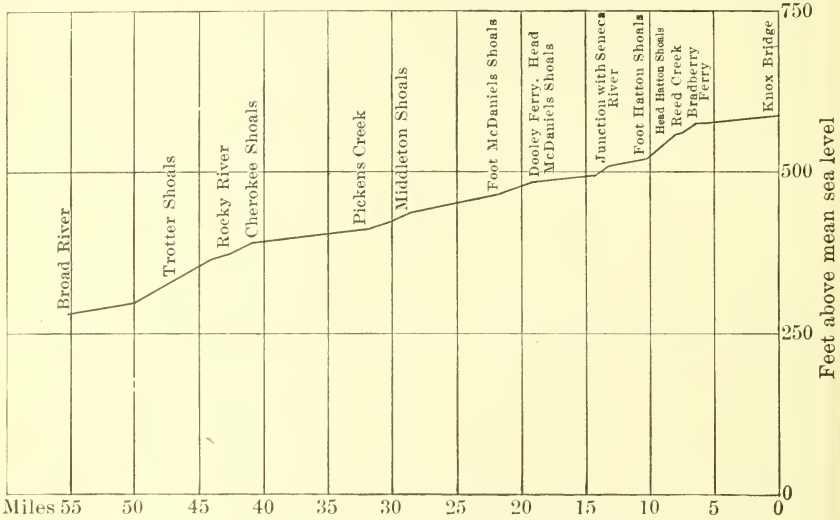


FIG. 3.—Profile of Tugaloo River below Tallulah Falls, Ga.

Elevations from Clarksville, via Turnerville, to Tallulah Falls, Ga.

	Elevation in feet
Clarksville, Habersham County court-house, north side of east entrance, bronze tablet marked "1373 Atlanta"	1,371.991
Clarksville, 0.7 mile southeast of, west side of road, nail in root of oak tree	1,436.353
Clarksville, 2 miles east of, south of track, nail in root of old stump	1,444
Clarksville, 1.5 miles east of station, dogwood tree, nail in root of	1,457.576
Clarksville, 2.5 miles east of, at railroad crossing, south of track, oak tree, nail in root of	1,419.40
Clarksville, 4.5 miles east of, oak stump, nail in root of	1,440.16
Clarksville, 6 miles east of, nail in root of oak tree	1,513.52
Clarksville, 7.5 miles east of, nail in root of oak tree	1,475.66
Turnerville station, 30 feet north of, nail in root of cottonwood tree	1,542.98
Turnerville, 1.9 miles northeast of, south of track, nail in root of oak tree	1,590.48
Turnerville, 3.2 miles northeast of station, nail in stump of gum tree	1,588.65
Turnerville, 4 miles northeast of, at road crossing east of track, nail in root of persimmon tree	1,612.33
Tallulah Lodge, 40 feet east of track, nail in side of hickory tree	1,605.84
Tallulah Falls station, 20 feet south of, 70 feet east of public road, rock, bronze tablet marked "1569 Atlanta"	1,568.302
Tallulah Falls, 0.5 mile north of east of, at forks of road, 50 feet south of bridge over river	1,457.92

Elevation from point 2 miles south of Tallulah Falls south down Tugaloo and Savannah rivers to mouth of Broad River, Lisbon, Ga.

	Elevation in feet.
Turnerville, 3.2 miles east of station, nail in stump of gum tree	1,588.65
Turnerville, 4.3 miles east of, nail in root of oak tree	1,504.20
Turnerville, 4.4 miles east of, nail in root of pine tree	1,386.10
Turnerville, 5.1 miles east of, south of road, point on rock	979.72

Elevations on Tugaloo River below Tallulah Falls.

Distance in miles.		Elevation in feet.
0.0	Junction of Tallulah and Chattooga rivers, 200 feet northwest of, gum tree, west side of Tallulah River, nail in root of gum tree	762.65
.0	Junction of rivers, 100 feet northwest of; edge of river, point on rock	761.29
.0	Junction of Tallulah and Chattooga rivers, water surface	754
.0	Tugaloo River, head of, pine tree, nail in root of	728.86
.7	Island, head of, surface of water	723
.8	Surface of water	711
2	Surface of water	698
2	West side of river, point on rock	698.79
2.1	Surface of water	690
2.4	Surface of water	686
2.8	Hickory tree, nail in root of	690.51
2.8	Surface of water	684
2.9	Surface of water	681
3.1	Small stream, mouth of, surface of water	674
4.4	Panther Creek, mouth of, surface of water	669
4.4	Panther Creek, 600 feet south of mouth and 50 feet west of river, west edge of public road, in large rock, bronze tablet marked "715 Atlanta"	713.793
5.3	Surface of water	667
5.4	Deaton Ford, surface of water	666
5.4	Small bridge, surface of water	664
5.4	Walnut tree, nail in root of	676.45
6.3	Surface of water	659
6.4	Small creek, South Carolina side, mouth of, surface of water	655
7.4	Walnut tree, 100 feet west of river, nail in root of	664.87
7.5	Small boat landing, surface of water	652
8	Big John Creek, mouth of, surface of water	650
8.9	Prather's bridge, 100 feet northwest of river and old bridge, cottonwood tree, nail in side of	659.02
8.9	Surface of water	648
9.9	James Prather homestead, middle step front entrance, bronze tablet marked "728 Atlanta"	726.873

Elevations on Tugaloo River below Tallulah Falls—Continued.

Distance in miles.		Elevation in feet.
10.5	Stream, mouth of, surface of water	646
11.5	Surface of water	644
11.5	Apple tree, 600 feet west of river, nail in root of	657.40
13	Stream, mouth of, surface of water	642
13	Gum tree, 10 feet west of river, nail in root of	658.51
13.8	Gum tree, west edge of river, nail in root of	651.33
13.8	Toccoa Creek, mouth of, surface of water	641
13.9	Jarrett Bridge, surface of water (during flood Mar. 21, 1903)	642.5
15.4	Water oak tree, 4 feet east of river, nail in root of	642.50
15.4	Walnut tree, 50 feet west of railroad bridge, nail in root of	660.52
15.4	Railroad bridge crossing Tugaloo River, west abutment, bronze tablet marked "666 Atlanta"	665.467
15.4	Stream, mouth of, surface of water	640
16.4	Stream, mouth of, surface of water	639
16.5	Sycamore tree, 50 feet south of river, nail in root of	641.09
16.5	Stream, mouth of, surface of water	637
17.5	50 feet east of river, birch tree, nail in root of	646.91
18	Surface of water	636
18	200 feet east of county road, 100 feet west of river, walnut tree, nail in root of	648.60
19	Saw mill, mouth of stream opposite, surface of water	632
19.1	Walnut tree, nail in root of	647.65
20.1	Stream, mouth of, surface of water	630
21.3	Swamp bush, 3 feet northwest of river, nail in top of	634.60
21.7	Rock Creek, 10 feet south of, walnut tree, nail in root of	640.35
21.7	Surface of water	624
22	Jenkins Ferry, 400 feet northwest of, 200 feet west of river, walnut tree, nail in root of	638.10
22	W. J. Perkins homestead, north side of house, in chimney, 2 feet above ground, bronze tablet marked "732 Atlanta"	[a] 730.754
22	Surface of water	624
22	High water	638
22.3	Stream, mouth of, surface of water	622
22.4	Walnut tree, nail in stump	635.56
22.6	Walnut tree, 40 feet west of river, nail in root of	634.32
23.2	Birch tree, on edge of small stream, nail in root of	629.55
24.5	Surface of water	618
24.5	Small tree, 4 feet west of river, nail in root of	619.47
25.1	Surface of water	616
25.5	Pine tree, 50 feet west of river, nail in root of	625.12
25.7	Surface of water	614

[a] The above is on a single spur line.

Elevations on Tugaloo River below Tallulah Falls—Continued.

Distance in miles.		Elevation in feet.
26.1	Old stump, 41 feet west of river, nail in	615.42
26.3	Head of Shelor Shoals, surface of water	610
27.6	Walnut tree, 10 feet north of river, nail in root of	614.54
27.6	Surface of water	607
27.9	Surface of water	605
28.1	Large creek, mouth of, surface of water	604
29.1	Pine tree, 5 feet northeast of river, nail in top of	623.27
29.3	Shelor Ferry, water oak tree, 10 feet northeast of river, nail in root of	606.46
29.3	Surface of water	600
29.3	Shelor Ferry, 0.3 mile southwest of; 100 feet northwest of I. E. Martin's house, 10 feet north of road, in large rock, bronze tablet marked "630 Atlanta"	628.875
30.1	Stream, mouth of, surface of water	599
30.3	Sycamore tree, 10 feet north of river, nail in root of	601.17
30.3	Mouth of stream, near bend in river, surface of water	597
30.4	Water oak stump, 10 feet north of river, nail in root of	598.10
30.4	Surface of water	595
31.8	Gum Log Creek, mouth of, surface of water	592
32.3	Near Middle Branch, apple tree, nail in root of	597.79
32.4	Surface of water	590
33.1	Surface of water	588
33.6	Knox Bridge, 100 feet west of, in fork of road, maple tree, nail in root of	602.73
33.6	Knox Bridge, 200 feet west of S. A. Glenn's house, in chimney, bronze tablet marked "613 Atlanta"	612.241
33.6	Surface of water	588
34.3	Surface of water	587
34.3	25 feet northwest of Shoal Creek, dead stump, nail in top of	598.34
35.3	Shoal Creek, mouth of, surface of water	586
35.3	Pine stump, 200 feet north of river, nail in top of	601.72
35.4	Knox Branch, mouth of, surface of water	586
36.1	Oak tree, 900 feet north of river, nail in root of	591.83
36.5	Burton Branch, mouth of, surface of water	582
37.5	South side of river, point on bottom of cliff	588.07
37.8	Pullins Ferry, 250 feet south of, 10 feet north of road, red oak tree, nail in root of	596.59
37.8	Pullins Ferry, surface of water	581
38.4	Cleveland Shoals, head of, surface of water	578
39.6	Averys Ferry, sycamore tree 10 feet north of river, nail in root of	584.36
39.6	Foot of shoals, surface of water	578
39.8	Bottom of cliff, 2 feet south of river, point on rock	581.95

Elevations on Tugaloo River below Tallulah Falls—Continued.

Distance in miles.		Elevation in feet.
39.8	Averys Ferry, 20 feet south of river, top of cliff, in rock, bronze tablet marked "588 Atlanta"	587.443
40.3	Bradberrys Ferry, walnut tree 100 feet south of river, nail in root of	581.95
40.3	Chandlers Shoals, head of, surface of water	575
40.7	Bottom of cliff, 1 foot south of river, point on rock	577.26
40.8	Beech tree, 1 foot south of river, nail in root of	572.24
40.8	Surface of water	570
40.9	Reed Creek, mouth of, surface of water	564
41.1	Foot of Chandlers Shoals, surface of water	562
41.4	Reed Creek, 900 feet east of 10 feet south of river, nail in stump	566.95
41.7	Boat landing, birch tree, nail in root of	563.72
42.3	Hatton Shoals, head of, surface of water	560
42.8	North edge of river, F. Clark's house, 1,000 feet south of, nail in root of maple tree	556.79
42.8	Surface of water	555
43.3	Big Beaverdam Creek, 25 feet east of, nail in root of beech tree	554.01
43.3	Surface of water	546
43.7	Large pine tree, 25 feet east of small stream, 5 feet north of river, nail in root of	537.07
43.7	Surface of water	535
44.2	Hatton Ford, bottom of cliff, point on rock	526.91
44.2	Surface of water	525
44.5	Mouth of branch, surface of water	522
44.7	Mouth of branch, surface of water	519
45.3	Water oak tree, 30 feet northeast of river, nail in root of	529.36
46.3	Beech tree, 15 feet east of river, nail in root of	525.17
46.3	Surface of water	519
46.6	Burnt stump, 40 feet east of river, nail in top of	524.70
46.6	Surface of water	518
47.7	Andersonville, S. C., 0.5 mile north of, twin beech tree 15 feet north of river, nail in root of	522.27
47.8	Mouth of branch, surface of water	516
48.2	Foot of rapids, surface of water	511
48.2	Andersonville, S. C., east side of road, 200 feet east of river, northwest of Little Broadway Creek, in rock, bronze tablet marked "538 Atlanta"	537.519
48.2	"Brouris" Ferry, surface of water	510
48.2	20 feet west of river, point on rock	514.45

SAVANNAH RIVER FROM ANDERSONVILLE, S. C., TO LISBON, GA.

Savannah River, which flows between Georgia and South Carolina, is formed by the junction of Seneca and Tugaloo rivers at Andersonville, Anderson County, S. C. Tugaloo River is in turn formed by the junction of Tallulah and Chattooga rivers at a point about 3 miles below Tallulah Falls, Georgia.

Savannah River proper flows in a southeasterly direction through a rather hilly country, which is chiefly devoted to the production of cotton and corn. On the lowlands these crops are sometimes damaged by high water. The river contains many small islands, some of which are in a high state of cultivation.

During April and May, 1903, a survey of Savannah River between Andersonville, S. C., and the mouth of Broad River, near Lisbon, Ga., a distance of 42 miles, was made by Carroll Caldwell, field assistant. In the above distance there is a fall of 219 feet. The primary levels for this survey were based on the United States Geological Survey bench mark at Andersonville, S. C. Field sheets were plotted on the scale of 1:22,500, and during the course of the survey 7 tablets and 62 temporary bench marks were established, 91 water-surface elevations determined, and the following possible powers noted.

The first shoal of importance is the McDaniels Shoal, where there is a fall of 19 feet in 2½ miles. Half a mile above the foot of the shoal and at the head of Harper Island is an excellent site for a dam about 700 feet long.

At Turners Shoals there is a fall of 17 feet in about 2½ miles. These shoals begin at Kenly Ferry and extend to Craft Ferry. The river widens considerably about a mile below Kenly Ferry and has several good sites, one being on Craft Island. These shoals could be developed only at considerable expense, as a dam would have to be 1,000 feet long.

Half a mile below, the Middleton Shoals have a fall of 11 feet in 1¼ miles and offer an excellent site for a dam. The bottoms and sides are of rock.

One mile below are Gregg Shoals with a 7-foot fall in about a mile. Here the river runs between steep hills and a dam would be about 900 feet long.

Half a mile below Moseley Ferry are the Cherokee Shoals, having a fall of 18.9 feet in less than 3 miles. This is a very fine power site, as the river runs between steep hills. A dam would be about 1,000 feet long and would be placed one-fourth of a mile above the Seaboard Air Line bridge.

One and one-fourth miles below the bridge are Trotters Shoals with a fall of 69 feet in 6 miles. These are considered the finest shoals

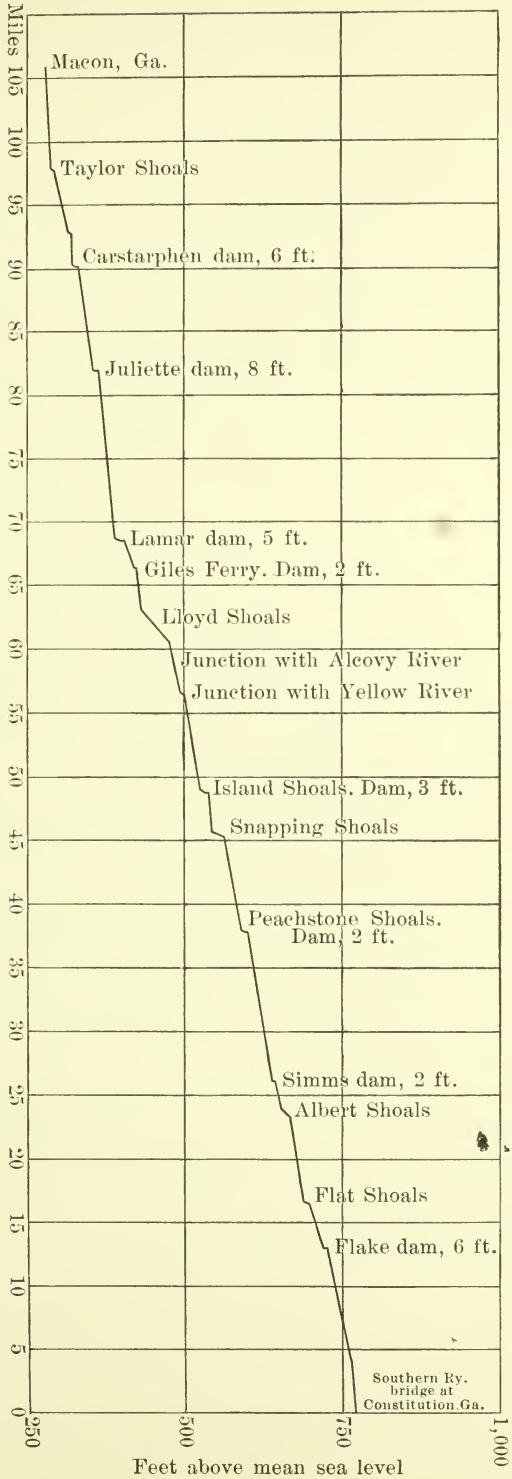
on the river. They commence at the foot of Watkins Island and run below Tates mill to Coffee Creek. In this distance there are numerous rocky bluffs where there are excellent dam sites.

From the foot of Trotters Shoals to the mouth of Broad River, the end of the survey, there is a uniform fall of 3 feet per mile.

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.[a]

Distance in miles.		Elevation in feet.
48.2	Andersonville, S. C., east side of road, 200 feet east of river, northeast of Little Broadway Creek, bronze tablet marked "538 Atlanta"	537.519
48.7	Seneca River, mouth of, surface of water	505
48.7	Small pine tree, nail in root of	512.60
49.3	Branch, mouth of, surface of water	501
49.3	Sycamore tree on edge of branch and river, nail in root of	502.78
50.5	Creek, mouth of, surface of water	497
50.6	Opposite island, 50 feet west of river, willow stump, nail in top of	503.38
50.7	Branch, mouth of, surface of water	493
51.4	In footpath, 10 feet west of river, large red oak tree, nail in root of	499.76
51.4	Lightwood Log Creek, 400 feet west of river, tripple water oak tree	507.28
52.3	Carters Ferry, surface of water	492
52.3	High water	516
52.3	Lightwood Log Creek, mouth of, surface of water	491
52.8	60 feet west of river, large walnut tree, nail in root of	501.09
53.3	Browns Ferry, 40 feet west of, double water oak tree, nail in root of	497.79
53.3	Surface of water	488
53.3	High water	499
53.3	Browns Ferry, 1,200 feet northeast of O. C. Brown's house, in brick and stone abutment at rear of, northwest corner, bronze tablet marked "518 Atlanta"	516.891
54.6	Powderbag Creek, mouth of, surface of water	487
54.8	Creek, 520 feet south of, 30 feet west of river, box elder tree, nail in root of	491.88
55	Dooley Ferry, 114 feet west of river, poplar tree, nail in root of	492.64
55	Surface of water	486
55.7	Craft Island, opposite, hanging over edge of river, maple tree, nail in root of	485.13
55.7	Surface of water	485
55.7	Long Branch, mouth of, surface of water	484
56.1	30 feet south of river, large poplar tree, nail in root of	487.61
56.1	Surface of water	482
56.1	McDowells Shoals, head of, surface of water	477
56.1	High-water mark	487
56.8	70 feet southwest of river, pine tree, nail in root of	483.26
56.8	Surface of water	474

[a] Continued from Tugaloo River elevations. See p. 28.



PROFILE OF SAVANNAH RIVER FROM ANDERSONVILLE, S. C., TO LISBON, GA.

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
57.3	Turner Creek, mouth of, southwest of river, birch tree, nail in root of	473.43
57.3	Surface of water	471
57.5	20 feet southwest of river, birch tree, nail in root of	476.13
57.5	Surface of water	470
58	Harper Island, 0.1 mile west of, red oak tree bending over edge of river, nail in root of	472.57
58.7	Surface of water	466
59.1	Parks Ferry, 0.2 mile above, west side of ferry road, opposite colored house, foot of steep hill, in cliff, bronze tablet marked "495 Atlanta"	494.435
59.3	Parks Ferry, 15 feet west of river, large red oak tree, nail in root of	468.53
59.3	Surface of water	461
59.5	Surface of water	460
60.5	Mulberry tree stump, west side of river, nail in root of	462.42
60.5	Surface of water	458
60.8	Saddlers Old Ferry, 40 feet west of river, rock cliff, point on rock	466.598
60.8	Surface of water	458
60.9	60 feet south of river, hickory tree, nail in root of	471.27
60.9	Surface of water	457
61.5	Cedar Creek, 500 feet north of river, large black oak tree, nail in root of	460.66
61.5	Cedar Creek, mouth of, surface of water	455
62.3	Kinleys Ferry, 0.1 mile southwest of; 10 feet west of river, white ash tree, nail in root of	457.68
62.3	Surface of water	454
62.4	Turners Shoals, head of, surface of water	453
62.5	McMullins Branch, mouth of, surface of water	450
64.2	50 feet south of river, small hickory tree, nail in root of	456.55
64.3	Shoals, surface of water	450
65.8	200 feet west of river, black oak tree, nail in root of	459.62
65.9	Surface of water	443
66.2	25 feet west of river, black oak tree, nail in root of	445.80
66.2	Surface of water	440
66.9	Craft Ferry, 10 feet west of river, red oak tree, nail in root of	443.67
66.9	Creek, mouth of, surface of water	437
66.9	Craft Ferry, 125 feet west of boat landing, 60 feet west of river, in rock, aluminum tablet marked "450 Atlanta"	449.306
66.9	Foot of Turners Shoals, surface of water	437
68.1	Middleton Shoals, head of, surface of water	435
68.5	Barnes Island, opposite, 125 feet west of river, small black oak tree, nail in root of	443.11
68.5	Surface of water	431
68.7	300 feet west of river, on top of cliff, dogwood tree, nail in root of	457.46

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
69.5	West edge of river, willow stump, nail in root of	428.03
69.8	Middleton Shoals, foot of, surface of water	424
69.8	20 feet west of river, post-oak tree, nail in root of	432.50
70.2	Powells Ferry, 20 feet west of river, water oak tree, nail in root of	435.23
70.2	Powells Ferry, surface of water	422
70.9	Surface of water	419
71	Powells Ferry, 0.8 mile south of, 150 feet west of river, white ash stob, nail in top of	439.30
71.3	Gregg Shoals, head of, surface of water	418.7
72.4	Black Ferry, 25 feet west of river, nail in root of birch tree	421.677
72.4	Black Ferry, surface of water	410.3
72.8	350 feet east of river, octagon burnt tree stump, nail in root of	431.08
73.2	Creek, mouth of, surface of water	409
73.4	350 feet east of river, persimmon tree stump, nail in root of	419.39
73.7	Branch, mouth of, surface of water	407
73.7	Mill, opposite, surface of water	406
73.8	Coldwater Creek, mouth of, surface of water	406
74.3	350 feet east of river, 140 feet southwest of small branch, persimmon tree, nail in root of	414.39
75.8	Allens Creek, mouth of, surface of water	404
76.2	Harper Ferry, 20 feet east of river, southside of road, water oak tree, nail in root of	412.26
76.2	Surface of water	403
76.2	High-water mark	416
76.4	250 feet southeast of W. J. Taylor's house, side of brook, in limestone rock, bronze tablet marked "420 Atlanta"	419.146
77	Branch, mouth of, surface of water	402
77.3	Ruckers and Tuckers Ferry, 40 feet southeast of and 5 feet west of river, willow tree, nail in side of	405.49
77.3	Surface of water	401
77.3	High-water mark	418
77.6	Surface of water	400
78.1	Surface of water	399
78.4	English Creek, 60 feet west of, 50 feet north of river, white hickory stump, nail in root of	417.13
78.4	English Creek, mouth of, surface of water	398
78.9	McCauleys Island, 900 feet south of head of, surface of water	397
79.2	McCauleys Ferry, 40 feet west of river, ash stump, nail in root of	407.19
79.2	Surface of water	397
79.6	Surface of water	396
79.6	150 feet north of river, beech tree, nail in root of	407.39
80.5	Branch, mouth of, surface of water	395
80.8	Surface of water	394

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
80.8	50 feet east of river, walnut tree, nail in root of	398.77
81	Moseley Ferry, 50 feet east of river, walnut tree, nail in root of	400
81	Surface of water	392
81.3	Surface of water	392
81.6	Surface of water	391
81.7	Large falls, head of, surface of water	390
81.8	50 feet east of river, twin pine tree, nail in root of	399.23
81.9	Cherokee Shoals, surface of water	388
82.6	Surface of water	379
82.6	125 feet east of river, oak tree, nail in root of	385.75
83.2	Surface of water	374
83.3	Carter Island, ferry, 40 feet west of river, white oak tree, nail in root of	382.52
83.5	Surface of water	373
83.7	Rocky River, mouth of, surface of water	372
84.2	Surface of water	371
84.2	Seaboard Air Line bridge, abutment, east side of bridge, bronze tablet marked "383 Atlanta"	382.161
85.1	Watkins Island, lower end of, 15 feet north of river, oak tree, nail in root of	375.7
85.2	Watkins Island, 150 feet southwest of, on mainland, dead stump, nail in side of	374.59
85.2	Trotter's shoals, head of, surface of water	367
85.5	Shoals, surface of water	364
85.7	Head of island, surface of water	362
85.9	Surface of water	358
86	75 feet west of river, nail in stub	367.4
86.2	Calhoun Island, end of, surface of water	356
86.3	60 feet southwest of river, black ash tree, nail in root of	365.01
86.3	Trotters Shoals, in, surface of water	353
86.6	Surface of water	351
86.6	Cliff, bottom of, on rock, point	354.27
87.1	Calhoun Ferry, triple cedar tree, 75 feet west of river, nail in root of	348.39
87.1	Surface of water	340
87.5	Surface of water	336
87.6	50 feet southwest of river, in path, pine tree, nail in root of	341.32
88.1	Creek, mouth of, surface of water	329.7
88.3	Surface of water	328
88.6	10 feet southeast of road, Spanish oak, 400 feet west of river, nail in root of tree	338.61
88.9	Surface of water	325
89.2	Surface of water	322

Elevations on Savannah River from Andersonville, S. C., to Lisbon, Ga.—Continued.

Distance in miles.		Elevation in feet.
89.2	200 feet west of river, on top of steep hill, in footpath, hickory tree, nail in root of	360.67
89.7	Calhoun Ferry, 2.5 miles southeast of, 50 feet west of river, in large bronze tablet marked "320 Atlanta"	319.252
89.4	Surface of water	318
89.7	Surface of water	313
90.1	Surface of water	308
90.2	Surface of water	304
90.3	10 feet west of river, 300 feet north of old mill, water oak, nail in root of	305.90
90.3	Surface of water	301
90.4	Surface of water	299
91.3	Branch, mouth of, surface of water	292
91.3	10 feet west of river, dead birch tree, nail in root of	300.21
91.8	Surface of water	291
92.3	Creek, surface of water	289
92.8	Clarks Ferry, 200 feet west of river, water oak, copper tack in root	309.13
92.8	Surface of water	287
92.8	High-water mark	307
93.7	Creek, 1,500 feet below, surface of water	285
93.9	50 feet west of river, gum tree, copper tack in side of	299.66
94.2	Surface of water	284
96.1	Petersburg Ferry, east side of road, dead black gum, nail in root of	293.41
96.1	Broad River, mouth of, surface of water	281
96.2	South side of ferry road, water oak, nail in root of	295.77
96.4	Lisbon, in brick wall of R. L. Cade's store, bronze tablet marked "328 Atlanta"	327.85

CHATTOOGA RIVER BELOW RUSSELL, S. C.

Between July 19 and August 10, 1903, Chattooga River was surveyed from its mouth, near Tallulah Falls, Georgia, to Russell Bridge, near Russell, S. C., a distance of 30 miles. In that distance there is a fall of 809 feet. A line of secondary levels was run, based on a primary bench mark of the United States Geological Survey 3 miles below Tallulah Falls. The field sheets were plotted on the scale of 1:22,500, and during the course of the survey 23 bench marks were established and 97 water-surface elevations were noted.

Chattooga River contains many available undeveloped power sites. From its mouth to War Woman Creek, a distance of 22 miles, the river runs through a wild, rugged country, almost uninhabited. It

flows in a gorge almost the entire distance and is very narrow and swift. There are numerous dam sites in this section, as the river is almost one continuous shoal and has an average fall of 33 feet to the mile, with a fine rock bottom and cliffs on either side. The rock is excellent for building purposes.

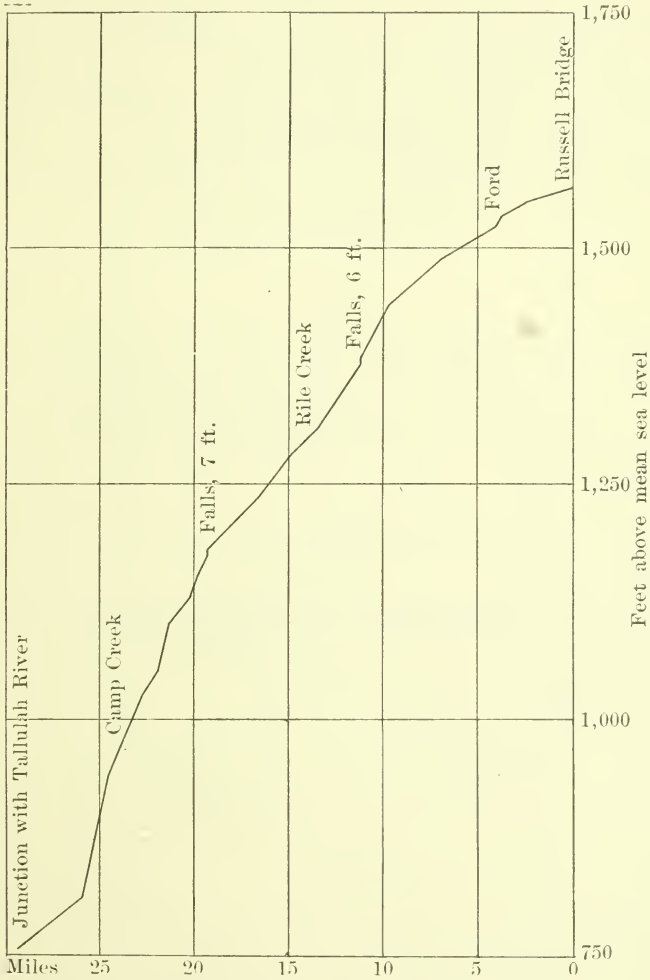


FIG. 4.—Profile of Chattooga River below Russell, S. C.

From War Woman Creek to Lone Bottom Ford, a distance of 5 miles, the bottoms widen considerably, and there are a few cultivated farms. Halfway, at Laurel Branch, there is an excellent site for a 12-foot dam, which would back water one-half mile without damage to cultivated lands. Here there is a good rock bottom and rocky bluffs on each side. From a half mile above Laurel Branch to Russell Bridge,

the end of the survey, the bottoms are considerably wider and mostly cultivated.

The elevations in the following list are based on an aluminum tablet marked "1050 M C" at Washington street entrance to the State capitol at Atlanta, the elevation of which is now accepted as 1,049.546 feet above mean sea level. The initial point upon which these levels depend is a bench mark of primary levels of Tugaloo and Savannah River surveys at the mouth of Chattooga River. The elevations accord with the 1903 adjustment.

The leveling was done under the direction of Carroll Caldwell, field assistant, by Thomas B. O'Hagan, levelman.

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.

Distance in miles.		Elevation in feet.
0.0	Tallulah and Chattooga rivers, 100 feet north of junction, point on rock	761.29
.0	Tallulah and Chattooga rivers, white oak tree 75 feet west of junction of, 25 feet north of Tallulah River, nail in root of oak tree	762.21
.0	Surface of water	754
.2	Surface of water	759
.7	Mouth of stream, surface of water	763
1	Worse Creek, mouth of, surface of water	765
1.2	Surface of water	766
1.9	Small stream on north edge of river, Spanish oak, nail in root of	776.27
1.9	Surface of water	772
2.1	Surface of water	775
2.6	North side of river, point on rock	788.63
3	Surface of water	779
4	East side of river, point on rock	851.51
4	Surface of water	849
4.1	Surface of water	869
4.5	Creek, mouth of, surface of water	892
4.7	Surface of water	899
4.9	East side of river, point on rock	918.27
4.9	Surface of water	919
5	Surface of water	929
5.1	Surface of water	939
5.2	Surface of water	949
5.3	Mouth of stream, head of shoals, surface of water	954
5.6	Camp Creek, mouth of, surface of water	961
5.6	Trail Ford, point on rock 20 feet east of river	967.50
5.6	Trail Ford, surface of water	962
5.8	Surface of water	969

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.—Continued.

Distance in miles.		Elevation in feet.
6.1	Surface of water	979
6.3	Surface of water	989
6.7	Surface of water	999
7	Surface of water	1,000
7.2	Surface of water	1,029
7.4	Cliff Creek, mouth of, surface of water	1,035
7.4	Cliff Creek, 500 feet above, east side river, point on rock	1,045.26
7.5	Surface of water	1,039
7.6	Chechero Creek, mouth of, surface of water	1,049
7.8	Surface of water	1,059
8	Surface of water	1,069
8.2	Surface of water	1,079
8.4	Surface of water	1,089
8.5	Surface of water	1,099
8.6	Surface of water	1,109
9	Surface of water	1,119
9.5	Surface of water	1,129
9.8	Surface of water	1,149
10	East side of river on edge of bank, point on rock	1,152.43
10	Surface of water	1,159
10	Iron bridge, South Carolina side, iron bar under bridge, point on	1,168.95
10	Iron bridge, surface of water	1,166.3
10	High water	1,177
10.5	Surface of water	1,169
10.6	Mouth of creek, surface of water	1,173
10.6	Head of falls, surface of water	1,179
10.8	Mouth of stream, surface of water	1,183
11	Surface of water	1,189
11.4	Surface of water	1,199
11.7	Mouth of stream, surface of water	1,204
12	Surface of water	1,209
12.5	50 feet south of island, east side of river, 10 feet from bank, point on rock	1,217.86
12.7	Surface of water	1,219
12.9	Surface of water	1,223
13	Surface of water	1,229
13.2	Stream, mouth of, surface of water	1,232
13.6	Surface of water	1,239
13.8	South Carolina side of river, at large cliff, point on rock	1,245.53
14	Surface of water	1,249
14	Mouth of Fall Creek, surface of water	1,262

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.—Continued.

Distance in miles.		Elevation in feet.
14.5	Surface of water	1,268
14.7	Surface of water	1,279
15	Surface of water	1,289
15.7	Surface of water	1,296
16	Surface of water	1,299
16.6	Rich Creek, mouth, surface of water	1,308
16.8	Surface of water	1,309
16.9	South Carolina side of river, point on rock	1,310.4
17	Surface of water	1,319
17.4	Surface of water	1,329
17.8	Sandy Bottom, 1,000 feet below, east side of river, point on rock	1,332
18	Surface of water	1,340
18.7	Surface of water	1,359
18.7	East side of river, point on rock	1,366.45
18.9	Surface of water	1,360
19.1	300 feet below falls, at bend in river, point on rock	1,376.19
19.2	Foot of falls, surface of water	1,375
19	Head of falls, surface of water	1,381
19.7	Surface of water	1,399
19.8	Rock Creek, mouth of, surface of water	1,406
20	Sandy Ford, surface of water	1,411
20	Sandy Ford, 75 feet north of, 15 feet east of river, nail in root of white oak tree	1,416.55
20.2	Surface of water	1,419
20.6	Surface of water	1,429
20.7	Dick Creek, mouth of, surface of water	1,439
20.8	Surface of water	1,449
21	East side of river, point on rock	1,452.91
21.2	Surface of water	1,459
22	Surface of water	1,469
22.1	Surface of water	1,473
22.3	4 feet east of river, nail in root of large pine tree	1,481.86
22.7	Surface of water	1,479
23	Earl Ford, 100 feet below ford, east side of river, point on rock	1,486.74
23	Surface of water	1,486
23	War Woman Creek, mouth of, surface of water	1,486
23.8	South side of river, point on rock	1,494.13
23.8	Surface of water	1,492
24.8	Surface of water	1,499
25.2	West side of river, point on rock	1,510.51
25.2	Surface of water	1,505

Elevations on Chattooga River from its mouth to Russell Bridge, Ga., 0.7 mile north of Russell, S. C.—Continued.

Distance in miles.		Elevation in feet.
26	Horseback Ford, surface of water	1,518
26.3	Surface of water	1,519
26.4	Ford, 65 feet above, north side of river, nail in live stub (white oak tree)	1,522.66
26.4	Surface of water	1,521
26.8	Surface of water	1,529
27.1	Surface of water	1,539
27.9	Barlow Stream, center of river, point on rock	1,547.26
28	Surface of water	1,549
28.7	Long Bottom Ford, east side, nail in fork of sugar maple tree	1,557.68
29.7	Small stream, mouth of river at, surface of water	1,554
30.6	West Fork, mouth of, surface of water	1,563
30.6	Wooden bridge, above Russell, S. C., southwest side of bridge, point on bolt	1,584.84
30.6	Bridge, surface of water	1,564

BROAD RIVER BELOW CARNESVILLE, GA.

Between June 9 and July 16, 1903, Broad River was surveyed from its mouth, near Lisbon, Ga., to Harrison Bridge, near Carnesville, Ga., a distance of 64½ miles. In that distance there is a fall of 316 feet. The field sheets were plotted on the scale of 1:22,500, and the survey was accompanied with a line of secondary levels based on the primary bench mark of the United States Geological Survey at Lisbon, Ga. During the course of the survey 54 bench marks were established and 109 water elevations determined.

The flow is very gradual from the mouth to Milford Shoals, a distance of 2 miles. These shoals have a fall of 8 feet in a distance of one-third of a mile, and are about 500 feet wide. The river bottoms are wide up to the foot of Anthony Shoals, 5¼ miles from the mouth of the river. Here is the finest power site on the river, there being a fall of 58 feet in 1¾ miles, with rock bottom and rock bluffs on each side. A dam at this point would have to be 1,000 feet long. The rock is granite and would furnish excellent material for building purposes. At the end of these shoals, on the Elbert County side, are the remains of a wing dam which furnished power for a cotton mill now in ruins.

From here to Fishdam Shoals, 9¼ miles, the river has a fall of 9 feet, with wide, cultivated bottoms on either side for most of the distance. At Fishdam there is a 3-foot dam about 250 feet long which furnishes power for a grist and saw mill.

From Fishdam to the mouth of South Broad River, 15½ miles, there is a fall of 23 feet with no shoal of any consequence. The bottoms are wide in most places and are in a high state of cultivation.

One mile above South Broad River are the Detwiler Shoals, with a fall of 7 feet in half a mile. A dam at this point would be about 300 feet long. A mile and a half farther are the lower Moore Shoals, with a fall of 6 feet in a quarter of a mile, and good outcrop of hard rock on both sides. A dam here would be about 350 feet long.

Five miles farther up are the Payton Shoals, with a fall of 4 feet in a quarter of a mile. Here the steep banks show granite on the southeast side.

Two and one-half miles upstream are the Cowpen Shoals, with a fall of 8 feet. This is an excellent site for a dam, having rock bottom and sides. Two miles upstream are Moore Shoals, with a fall

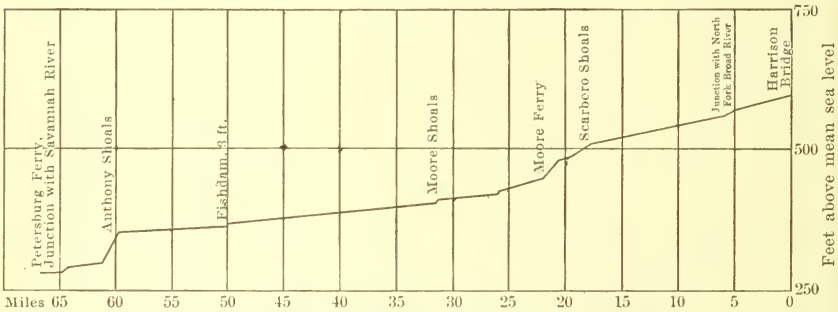


FIG. 5.—Profile of Broad River below Carnesville, Ga.

of 19 feet in three-fourths of a mile. The river here is about 400 feet wide, with solid rock bluffs on either side.

One-half mile beyond are Brown Shoals, with a 10-foot fall in one-third of a mile. A dam here would be about 400 feet long and would have an excellent foundation. One and three-fourths miles upstream are the Bryant Shoals, with a fall of 20 feet in 1¼ miles. This is an excellent site for a dam, having good bottoms and rock sides.

For 12 miles upstream to Double Bridge the shoals are small and do not seem important. From Double Bridge to Harrison Bridge, at which point the survey ended, a distance of 6 miles, the river is very narrow and shoaly, but the volume of water is small.

The elevations in the following list are based on a bronze tablet in a brick wall of R. L. Cade's store at Lisbon, Ga., marked "Atlanta 328," the elevation of which is accepted as 327.850 feet above mean sea level. They accord with the 1903 adjustment of the precise-level net.

The leveling was done under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville.

Distance in miles.		Elevation in feet.
0.0	Lisbon, mouth of Broad River, 870 feet northwest of, south side of ferry road, nail in twin water oak	295.77
.0	Broad River, mouth of, surface of water	280
.0	Broad River, 870 feet northwest of mouth, high-water bench mark	300
.6	Small stream, near, surface of water	281
1.4	Mill Ford Shoals, foot of, surface of waters	281
2.1	Mill Ford Shoals, middle of, surface of water	288
2.4	Mill Ford Shoals, head of, surface of water	289
2.4	Mill Ford Shoals, 200 feet east of river, near 5-inch elm tree, nail in live stob	304.9
2.7	Center of bend, surface of water	291
3.4	Dubose Ferry, 300 feet above, surface of water	292
4.7	Anthony Shoals, foot of, surface of water	293
5	Anthony Shoals, surface of water	295
5.2	Anthony Shoals, at large bend in river, surface of water	307
5.2	Anthony Shoals, at rock cliff, surface of water	310
5.2	Anthony Shoals, at rock cliff, point on rock, 1 foot west of river	311.57
5.4	Anthony Shoals, surface of water	319
5.6	Anthony Shoals, surface of water	329
5.8	Anthony Shoals, in front of old factory, surface of water	339
6	Anthony Shoals, at old dam, east edge of river, nail in root of birch tree	347.77
6	Anthony Shoals, surface of water	351
6.4	Anthony Shoals, head of, surface of water	355
6.5	Burton Ferry, 6 feet south of river, nail in root of Spanish oak tree	361.44
6.5	Surface of water	355
6.5	Burton Ferry, high water	364
7.1	Surface of water	355
8.7	Mouth of creek, surface of water	356
8.7	60 feet south of river, 25 feet east of creek, nail in sweet gum tree	367.59
10	Surface of water	356
10.9	Bakers Ferry, small shoals, surface of water	356
11	Bakers Ferry, 20 feet southwest of river, nail in root of large birch tree	364
11	Bakers Ferry, surface of water	357
11.8	Wahache Creek, mouth of, surface of water	360
13.8	Bells Bridge, north side, nail in joist	373.69
13.8	Bells Bridge, surface of water	360
13.8	Bells Bridge, high water	386
13.8	Bells Bridge, floor of	393.2
15	Bells Bridge, 250 feet north of river, large pine tree near path to river, nail in tree	375.34
15.4	Mouth of small stream, surface of water	361
15.6	Falling Creek, mouth of, surface of water	362

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
16	Foot of shoals, surface of water	363
16.4	Fishdam, foot of, surface of water	365
16.4	Fishdam, head of, surface of water	368
16.4	Fishdam Ferry, north side river, nail in root of large water oak tree	374.35
16.4	Fishdam Ferry, surface of water	368
16.4	Fishdam Ferry, south side of, nail in root of gum tree	374.87
17.7	Surface of water	368
18.9	North of river, point on rock	386.66
18.9	Surface of water	370
20	Grimes old ferry, edge of river, nail in root of white oak tree	375.51
20	Grimes old ferry, surface of water	371
21.3	500 feet south of river, river road, 25 feet south of, nail in root of Spanish oak	388.89
22.1	Mouth of large creek, surface of water	372.8
22.5	Pinegrove, 400 feet north of river, 900 feet west of large creek, nail in root of pine tree	398.51
23.1	Mattox Bridge, north side, nail in plank	401.35
23.1	Mattox Bridge, surface of water	374
23.1	Bridge floor	404
23.1	High water	400
24.8	Rock cliff, near, 40 feet south of river, nail in root of gum tree	397.88
24.8	Surface of water	377
25.2	Jones Ferry, east side, nail in root of water oak tree	393.43
25.2	Jones Ferry, surface of water	377
25.2	High-water mark	401
25.5	Jones Ferry, 0.3 mile above, 40 feet west of river, nail in white oak tree	394.38
26	Surface of water	380
26.7	Millstone Creek, mouth of, 60 feet east of, 25 feet south of river, nail in side of box elder	392.64
26.7	Millstone Creek, mouth of, surface of water	381
28	Gold Mine Cliff, surface of water	384
28.5	Horseshoe Bend, head of, 150 feet south of river, in cornfield, nail in Spanish oak	405.67
28.5	Dove Creek, mouth of, surface of water	386
28.6	Bend in river, surface of water	396.4
28.6	Surface of water	386
30	260 feet north of river, nail in root of pine tree	411.3
30.9	Surface of water	391
31	Martins old ferry, near spring, point on rock	420.14
31.3	Junction South Fork and Broad River, southeast point of rivers, nail in side of birch tree	395.86
31.3	Surface of water	391

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
32.4	Detwiler Ferry, foot of shoals, surface of water	395
32.9	Detwiler Ferry, east side, edge of water, slanting Spanish oak, nail in	406.07
32.9	Detwiler Ferry, head of shoals, surface of water	402.1
32.9	Detwiler Ferry, high water	423.6
33.4	Seaboard Air Line bridge, abutment, east side of river, 350 feet from	420.28
33.4	Seaboard Air Line bridge, surface of water	402
34	Moore Shoals, surface of water	404
34.4	Old mill, 25 feet east of river, point on rock	416.23
34.4	Old mill, mouth of stream, surface of water	409
34.4	Moore Shoals, head of, surface of water	411
34.7	Bells Ferry, edge of river, 2 feet from road, overhanging Spanish oak, nail in	418.87
34.7	Bells Ferry, surface of water	412.3
34.7	Bells Ferry, high water	430
35.9	Harpers Ferry, north side of river, east side ferry, nail in root of black gum tree	422.54
35.9	Harpers Ferry, surface of water	414
35.9	Harpers Ferry, high water	432
36.8	Holly Branch, mouth of, surface of water	416
37.5	Moon Ferry, east of ferry, nail in side of white oak tree	423.19
37.5	Moon Ferry, surface of water	418
37.8	Surface of water	419
37.9	Mouth of creek, surface of water	420
38.6	Payton Shoals, foot of, surface of water	422
39	Payton Shoals, east side of river, nail in sycamore tree	428.57
39	Payton Shoals, head of shoals, surface of water	425
39.1	South Payton Ferry, 25 feet from river, east side of ferry, nail in side of dead willow tree	431.35
39.1	Payton Ferry, high water	449
39.1	Payton Ferry, surface of water	427
39.1	Payton Ferry, high water	449
39.4	Payton No. 2, head of shoals, surface of water	429
39.8	Victory Ferry, overhanging birch tree, nail in side of	432.17
39.8	Victory Ferry, surface of water	430
39.8	High water	450
40.4	Moon Ferry, nail in root of white oak tree	442.62
40.4	Moon Ferry, foot of shoals, surface of water	431
40.5	Moons Shoals, head of, surface of water	433
41.1	Bend in river, 1,500 feet east of Mill Creek, east side river, point on rock	443.14
41.1	Surface of water	438

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
41.4	Mill Shoal Creek, mouth of, surface of water	439
41.4	Surface of water	441
42.2	Head of shoals, surface of water	450
42.7	Moore Ferry, west side of, large spruce oak tree, nail	455.77
42.7	Moore Ferry, surface of water	450
42.7	High water	460
43.0	Moore Shoal, at spring, foot of shoals, surface of water	454
43.3	Shoals, surface of water	462
43.3	Moore Shoals, near head of, point on rock	470
43.8	Browns Ferry, burnt stump northeast of river, nail in	482.09
43.8	Browns Ferry, near head of Moors shoals, surface of water	471
44.2	Moore Shoals, head of, surface of water	482
44.6	Dudleys Shoals, east bank of river, point on rock	489.28
44.6	Surface of water	482
45.5	Dudley Ferry, black gum tree north side of ferry, nail in root	502
45.5	Dudley Ferry, surface of water	487
45.5	High-water mark	504
45.6	Bryant Shoals, foot of, surface of water	489
46.2	Bryant Shoals, head of, surface of water	496
46.5	Sawmill, Spanish oak tree, 50 feet from river, nail in root of	506.65
46.5	Surface of water	502
46.5	Head of shoals, surface of water	506
47.7	Bluestone Creek, north side river, 1.2 miles below Bluestone Creek, point on rock	518.38
47.7	Surface of water	512
48.9	Mouth of Bluestone Creek, surface of water	617
49.6	Surface of water	521
50.4	New Lattice Bridge, east side of river, nail in floor of	546.44
50.4	Bridge floor	548.8
50.4	Bridge, surface of water	523
50.4	High-water mark	548.1
51.2	Mouth of stream, foot of shoals, surface of water	523.7
51.6	Head of shoals, surface of water	526
52.3	Winters Creek, just below bend in river, surface of water, temporary bench mark	545
52.4	Winters Creek, mouth of, head of shoals, surface of water	529
53.2	Surface of water	532
53.9	Mouth of stream, surface of water	535
54.7	Bragg Ferry, 2 feet from river, nail in root large red oak tree	541.75
54.7	Bragg Ferry, mouth of Hudson River, surface of water	537
54.7	High-water mark	567

Elevations on Broad River from mouth to Harrison Bridge, 3 miles southwest of Carnesville—Continued.

Distance in miles.		Elevation in feet.
55.2	Surface of water	541
55.7	Dove Bridge, southeast corner of, nail in side of white oak tree	561.78
55.7	Dove Bridge, surface of water	542
55.7	High water	569
57.2	Foot of shoals, surface of water	548
57.3	Head of shoals, surface of water	552
57.6	Surface of water	554
57.7	Creek, 60 feet southeast of mouth of, nail in white oak	563.30
57.7	Creek, mouth of, surface of water	556
58.1	Mouth of stream, surface of water	556
58.8	Middle Broad and Broad rivers, forks of, walnut tree 75 feet west of fork, nail in side	575.16
58.8	Surface of water	557
59.1	Double Bridge, northwest side of, nail in plank	581.11
59.1	Surface of water	563
59.1	High-water mark	576
59.1	Bridge floor	584
59.7	Head of shoals, surface of water	570
59.9	Surface of water	573
60.6	Corey Creek, 0.6 mile below, large rock projecting out from bank point on	581.02
60.9	Small shoals in river, surface of water	580
60.9	Corey Creek, mouth of, surface of water	581
61.5	Bend, on east side river, point on rock	591.15
61.5	Surface of water	584
62.1	Fish dam, surface of water	586
62.2	Surface of water	588
62.3	Bend in river, east side, point on rock cliff	598.59
62.8	Philip Shoals, head of, surface of water	591
63.2	Stephens Creek, mouth of, surface of water	592
63.4	Ford, oak tree 75 feet north of, nail in north side of	603.49
63.4	Surface of water	593
63.4	Surface of water	594
64.6	Harrison Bridge, east of, north of river, nail in root of Spanish oak tree	607.07
64.6	Surface of water	596
64.6	Bridge floor	613.7
64.6	High-water mark	612

SOUTH AND OCMULGEE RIVERS, FROM CONSTITUTION TO MACON, GA.

South and Ocmulgee rivers were surveyed from Constitution to Macon, Ga. For the first 28 miles the topography was plotted on the scale of 1:45,000, but subsequently on the standard scale of 1:22,500. The levels are secondar levels based on the United States Geological Survey permanent bench mark at Constitution, Ga. Eighty-six bench marks were established and 200 water-surface elevations were recorded.

South River rises in the city of Atlanta and flows in a southeasterly direction for 56½ miles and then joins Yellow River to form the Ocmulgee. For 11 or 12 miles below Constitution, the beginning of the survey, the river is narrow, being about 15 feet wide at places. All along the north side of the river in this stretch are extensive beds of clay, which at certain points are being used for brickmaking.

Flakes' mill, 11 miles from Constitution, is the first power now utilized on the river. At this point the dam is 6 feet high. Below for 6 miles the river remains shoaly and narrow until Flat Shoal is reached, where there is a fall of 12 feet with a small gristmill using a little of the power. Near here the river is very crooked and incloses in its large loops flat, sandy stretches of country, which are very fertile. Near Flat Shoal is Littlestone Mountain, with valuable granite quarries.

At Albert Shoals, 7 miles farther down, there is a fall of 16 feet in half a mile. The river is here about 125 feet wide and the volume is much increased by a number of tributary streams. The banks are sloping, with no rock visible. The power site has recently been purchased by a company which proposes to develop it.

At Simm's mill, 3 miles below, is a small 2-foot dam. From here to Peachstone Shoals, a distance of 11 miles, there is a fall of 32 feet, the river winding through good bottom lands. Camp and Honey creeks enter the river in this stretch and add a large amount of water. At Peachstone Shoals is a 2-foot dam which backs the water for one-half mile, and with a canal about 400 feet long develops a head of about 9 feet, the power from which drives several turbines operating a grist and a saw mill. Soft rock is visible on the west bank, while the east bank is a flat sand bar.

About 8 miles below are the Snapping Shoals, where there is a fall of 20 feet in a distance of 300 yards. Near the lower end of the rapids several small islands divide the channel into several parts. Solid rock is close to the surface on both sides of the river. A portion of the power at this point is used in operating a large roller flour mill and sawmill. Mr. DeLoach, the owner, is taking steps

to develop all the power and intends erecting a large cotton factory at this point.

Three miles below here is Island Shoal, with a fall of 10 feet in 250 yards. Here there is a flour mill and a furniture factory, both operated by a 3-foot dam with a canal 1,200 feet long. The head could be increased by adding 5 feet more to this dam without materially damaging any property above. This site is an excellent location for power development, as the banks are high and solid and the length of the dam would probably not exceed 250 feet.

Eight miles farther down is the Barnes Shoal, at the mouth of Yellow River. A dam here would be about 700 feet long. There are excellent foundations and about a 9-foot fall.

Farther down the stream are Keys Shoals, with a 3-foot fall and several minor riffles to Lloyds Shoals, which has a fall of 43 feet in about 2½ miles, at the lower end of which there is a good dam site. The river at this point is only about 350 feet wide, with solid rocky banks rising 50 feet on either side. A 45-foot dam at this point would do a trifling amount of damage to property above.

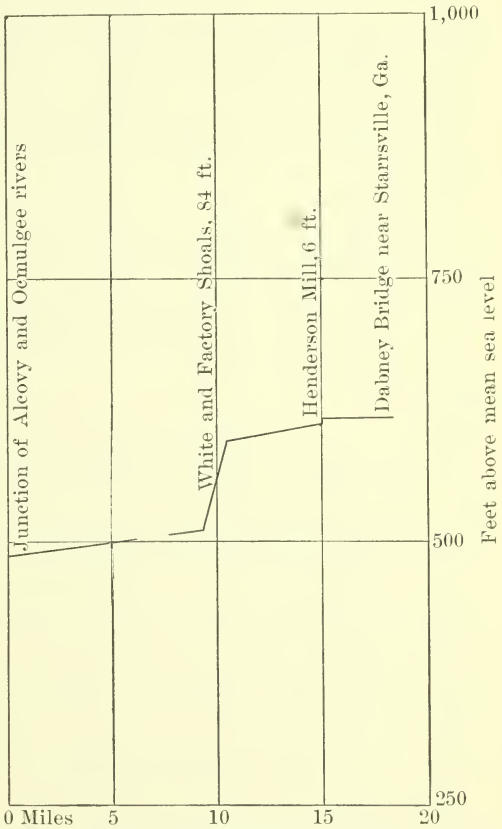


FIG. 6.—Profile of South and Ocmulgee rivers from Constitution to Macon, Ga.

Ten miles downstream is Smith Shoal, with a fall of 12 feet, where a 2-foot dam and a long canal at present run Smith's gristmill. At Lamars Shoals, 2 miles below, there is a fall of 19 feet in 1 mile with a 5-foot dam and a canal running a flour mill. The river is here about 1,000 feet wide, with high, rocky banks, and has a number of small islands and large rocks scattered all through it. Twelve miles farther down, at Juliette, Ga., is an important shoal which has been developed by Doctor Glover. There is a 15-foot fall in one-half mile, which has been developed by an 8-foot dam with a short canal,

and runs the Glover cotton mills and the Juliette Milling Company's plant.

Twelve miles below are Dames Shoals, with an 8-foot fall in 600 feet. A 6-foot dam at this point supplies Carstarphens gristmill, which is a large wholesale plant. The bed of the river here is solid rock, but a higher dam would flood valuable bottom lands above.

Popes Shoals have a 5-foot fall in a quarter of a mile, and Taylor's shoals have a 5-foot fall within a few hundred yards.

The elevations in the following lists are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta marked "1050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level. The leveling on South and Ocmulgee rivers is adjusted to accord with elevations of precise level bench marks at Constitution, Holton, and Macon, Ga., by the 1903 adjustment.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, level man.

Elevations on South River from Constitution to junction with Yellow River (head of Ocmulgee River) near Worthville.

Distance in miles.		Elevation in feet.
0.0	Constitution, 25 feet south of Southern Railroad, 4 feet east of sign-board, iron post marked "847 Morehead 1898"	847.006
.0	Surface of water	772
2	Intrenchment Creek, mouth of, nail in root of black gum	773.77
2	Surface of water	770
2.8	McNeals Bridge, nail in root of sycamore tree	769.57
2.8	Surface of water	768
7	Kellers Bridge, north end, iron bolt	751.92
7	Surface of water	750
10	Shoal Creek bridge, surface of water	737
12.6	Flake's mill, nail in root of birch tree	733.26
12.6	Surface of water	728
16.3	Flat Shoal Bridge, south side of river, east side of approach, on stone abutment	708.71
16.3	Surface of water	698
	Foot of shoal	686
20.6	Parkers Bridge, nail in root of sweet-gum tree	678.76
20.6	Surface of water	672
23.6	Daniels Bridge, lower side, right end of, point of stone pier	667.97
23.6	Surface of water	649
25.3	Simms Bridge, surface of water	635
26.4	Knight Creek, 50 feet above mouth, on root of sycamore, nail	639.28
26.4	Surface of water	629

Elevations on South River from Constitution to junction with Yellow River (head of Ocmulgee River) near Worthville—Continued.

Distance in miles.		Elevation in feet.
31	Oglesbys Bridge, 25 feet above, nail in root of oak tree	622.02
31	Surface of water	614
36	Peachstone Falls, nail in root of water oak	605.71
36	Peachstone Shoals, head of, surface of water	597
	Peachstone Shoals, foot of, surface of water	589
41	Butler Bridge, 30 feet below, nail in root of red-oak tree	587.15
41	Surface of water	569
43	Snapping Shoals, head of, surface of water	562
43.1	Snapping Shoals Bridge, 40 feet from north approach, on root of water oak	559.66
	Snapping Shoals, foot of, surface of water	542
	Island Shoals, head of, surface of water	536
45.3	Island Shoals Bridge, near south approach of, nail in root of white oak	534.89
45.3	Surface of water	525
50.8	Manns Bridge, on south side of river, 20 feet below, nail in root of hickory tree	518.49
50.8	Surface of water	503
52.1	Yellow River, mouth of, opposite, nail in root of pine tree	506.94
52.1	Surface of water	498

Elevations on Ocmulgee River from head, at junction of South and Yellow rivers, near Worthville, to Macon.

Distance in miles.		Elevation in feet.
0.0	Yellow River, opposite mouth of, nail in root of pine	506.94
.0	Surface of water	498
	Alcovy River, opposite mouth of, nail in root of large white oak	494.27
	Surface of water	484
4.1	Tusahaw Creek, mouth of, head of Lloyds Shoals, nail in root of water oak	482.12
4.1	Surface of water	472
6.4	Lloyds Shoals, foot of, surface of water	429
7.4	Pittmans Ferry, near south side of, nail in root of beech tree	434.96
7.4	Surface of water	425
7.9	Yellow Water Creek, 30 feet above mouth of, nail in root of hickory tree	433.97
7.9	Surface of water	422
9.2	Giles Ferry, nail in root of pine tree	430.01
9.2	Surface of water	420

Elevations on Ocmulgee River from head, at junction of South and Yellow rivers, near Worthville, to Macon—Continued.

Distance in miles.		Elevation in feet.
9.2	Smiths Shoals, head of, surface of water	420
10.7	Smiths Shoals, foot of, surface of water	408
10.9	Smiths Ferry, on south side, 20 feet above landing, nail in root of ash tree	410.44
10.9	Surface of water	407
11.9	Lemars Shoals, head of, surface of water	406
11.9	Lemars Shoals, foot of, surface of water	387
14.1	Goodmans Ferry, south side of river, nail in root of large red oak tree	400.74
14.1	Surface of water	382
17.8	Wards Ferry, south side of river, nail in root of water oak	392.69
17.8	Surface of water	375
19.4	Big Sandy Creek, Southern Railway bridge over, 4 feet south of rail, 2 feet from east end bridge, point on stone pier	399.45
19.4	Surface of water	374
22.5	Bridges Ferry, south side of river, nail in root of large water oak tree	382.82
22.5	Surface of water	370
22.9	South bank river, 10 feet from water, nail in root of large oak tree	388.15
22.9	Surface of water	368
24.4	Towaliga River, south bank at mouth of, nail in root of red oak	379.34
24.4	Surface of water	368
25.4	Glovers Shoals, head of, surface of water	366
25.9	Glovers Shoals, foot of, surface of water	351
27.3	Glovers Ferry, 10 feet south of west approach, nail in root of beech tree	361.10
27.3	Surface of water	346
28.5	Mitchells Ferry, 10 feet south of west end, nail in root of red oak tree	361.74
28.5	Surface of water	344
32.4	25 feet from river, opposite milepost, nail in root of thunderwood tree	340.79
32.4	Surface of water	330
33.9	Danns Ferry, 10 feet south of west end of, nail in root of ash tree	335.63
33.9	Surface of water	328
34.9	Carstarphens Shoals and dam, head of, surface of water	328
	Foot of dam, surface of water	322
35	Foot of shoals, surface of water	320
36.4	Rum Creek, north abutment west end of Southern Railway bridge over	347.32
36.4	Surface of water	318
36.9	Popes Station, in front of, top of west rail	348.23
36.9	Popes Ferry, south end of, nail in root of water oak	326.88
36.9	Surface of water	318
37.9	Head of shoals, surface of water	317
37.9	Foot of shoals, surface of water	312

Elevations on Ocmulgee River from head, at junction of South and Yellow rivers, near Worthville, to Macon—Continued.

Distance in miles.		Elevation in feet.
41.9	Holton, 35 feet north of station; 29 feet west of center of track, iron post marked "339 Morehead 1898"	338.733
41.9	Surface of water	299
47.7	Virgin, west rail of upper switch of Southern Railway at	322.52
47.7	Surface of water	282
49.9	Macon waterworks, just below, 30 feet east of track, 100 feet below mouth of small creek on south side of river, nail in root of pine tree	301.88
49.9	Surface of water	278
54.9	Macon, post-office building, at corner of Mulberry and Third streets, at left of Mulberry street entrance, in water table, aluminum tablet marked "334 Morehead 1898"	333.942

YELLOW RIVER BELOW YELLOW RIVER, GA.

Yellow River was surveyed from its mouth, near Worthville, Ga., upstream to Simmons's mill, near Yellow River, Ga., a distance of 57 miles. The scale upon which the field work is plotted is 1:22,500. During the course of the survey 54 bench marks were established and 103 water-surface elevations obtained.

Yellow River flows in a southeasterly direction and contains some valuable power sites, both developed and in a natural condition. One-half mile above its mouth are the Indian Fishery Shoals, where there is a fall of 12 feet in about 200 feet. The river is here about 300 feet wide, but a narrow neck projecting just below the shoals and several rocky islands considerably reduce the probable expense of construction. There is a gristmill and a cotton gin in operation here, using perhaps nine-tenths of the available power.

For 18 miles above the river runs between high banks, alternating with low bottoms to Langdon Shoals, without any marked shoals except at Lees, where there is a fall of 2½ feet, and Flat Shoals, with a 1-foot fall. Langdon Shoals have only a 4-foot fall.

Three miles above, at Porterdale, is the finest power site on the river, where extensive developments have been made by the Bibb Manufacturing Company, which has a large cotton and twine factory at this point. Here there is a fall of 67 feet in half a mile, with a 12-foot dam at the upper end of the shoal. The banks at the foot are very high, but gradually become lower until just above the dam large bottoms begin and continue for 5 miles. Five miles above the Georgia Railroad is the next power, McDaniels Shoals, where there is a 7-foot fall in a very short distance, and a 6-foot dam operating a gristmill. The north bank is solid rock, sloping gently, but

the south bank shows no outcrop. The power developed by this dam could be much increased with small cost.

Above this point the bottoms become narrower and the river banks more rugged and higher until at Milstead, Ga., 4½ miles above, there is a fall of 45 feet in half a mile. A 15-foot dam, with canal, is completed here, and two large cotton factories are being constructed. Railroad facilities have recently made this a valuable site for mills, and a large granite quarry has been opened up at the same point.

Eleven miles above are Anniestown Shoals, with a 23-foot fall, where there is an 11-foot dam, which formerly supplied power used to operate a cotton mill of the old type. The banks here are all hard, unseamed rock, and the site could be developed into valuable property.

Two and one-half miles above are some shoals with a 14-foot fall in half a mile. The power is undeveloped, but is in a rather inaccessible

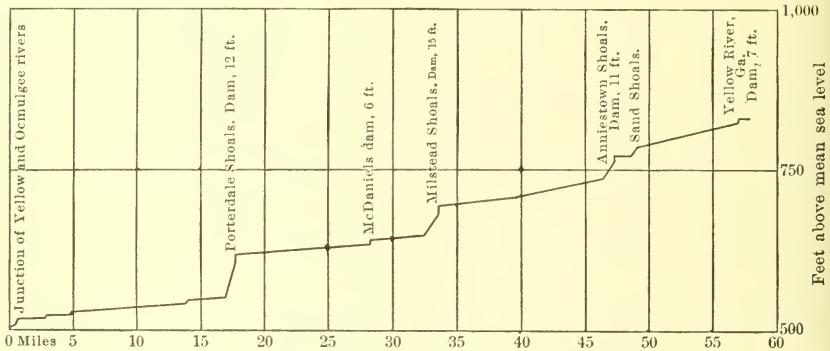


Fig. 7.—Profile of Yellow River below Yellow River, Ga.

section of the country. Above this point the river flows through a very rough country for 10 miles, passing no important shoals until the next power is reached, at Yellow River, Ga., the end of the survey. Here is a dam 7.3 feet high, which operates the Simmons roller mills. The lower reaches of the river are thickly settled, cotton and grain being the principal crops, but the upper part of the river is almost entirely in timber land.

The elevations in the following list are based on an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta, marked "1,050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level. The initial point of this list is a bench mark of flying levels on Ocmulgee River.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Yellow River from mouth near Worthville to Yellow River, Ga.

Distance in miles.		Elevation in feet.
0.0	Yellow River, mouth of, opposite, nail in root of pine tree	506.94
.0	Surface of water	500
.5	Indian Fishery Shoals, 10 feet of from water, nail in root of ash tree	517.24
.5	Foot of shoals, surface of water	504
.0	Head of Indian Fishery Shoals, surface of water	516
2.5	Allens bridge, east bank, 20 feet from river, nail in root of maple tree	528.49
2.5	Surface of water	517
4.7	Lees Shoals, foot of, west bank, nail in root of ash tree	528.49
4.7	Surface of water	520
	Lees Shoals, head of, surface of water	523
6.2	Pickett Bridge, on east bank, nail in root of white oak	539.23
6.2	Surface of water	526
10.7	Flat Shoal Bridge, west bank, nail in root of white oak	551.24
10.7	Surface of water	534
13.8	Langdons Shoals, west bank, 15 feet from river, nail in root of white oak	549.69
13.8	Surface of water	539
	Langdons Shoals, head of, surface of water	543
16.9	Porterdale Shoals, foot of, 10 feet from river, west bank, nail in root of white oak	561.05
16.9	Surface of water	549
	Porterdale dam, foot of, surface of water	604
	Porterdale dam, head of, surface of water	616
17.7	Porterdale, 30 feet from dam, 20 feet from south approach, nail in root of white oak	618.38
17.7	Surface of water	616
17.7	Wagon bridge, east side of river, at extreme south end of bridge, top of steel post of railing	627.81
20.8	Browns Bridge, 60 feet above, 10 feet from river, on root of gum tree	622.81
20.8	Surface of water	611.6
22.8	Tin Bridge, on west bank river, nail in root of poplar tree	627.49
22.8	Surface of water	617
23	Georgia Railroad bridge, west side of river, on top of rock, chisel mark	642.05
23	Surface of water	617
24.3	Hendricks Bridge, north bank of river, nail in root of water oak	639.11
26	Haynes Creek, opposite mouth of, nail in root of water oak	632.26
26	Surface of water	624.6
28.2	McDaniels Bridge, west bank of river, nail in root of large water oak	644.17
28.2	Surface of water	632
	McDaniels dam, head of, surface of water	641
30.5	West side of river, Pine Log Bridge, 10 feet below, nail in root of pine	650.55
30.5	Surface of water	641

Elevations on Yellow River from mouth near Worthville to Yellow River, Ga.—Continued.

Distance in miles.		Elevation in feet.
32.2	Botosh Creek, 100 yards above mouth of, left bank of river, nail in root of pine	653.96
32.2	Surface of water	644
32.8	Foot of Milstead Shoals, west bank, nail in pine tree	657.41
32.8	Surface of water	647
33	Milstead, foot of dam, surface of water	677
33	Milstead, top of dam, surface of water	692
33	40 feet above wagon bridge, on south side of river, nail in root of large white oak	701.33
33	Surface of water	692
35.4	Irvins Bridge, 20 feet above, left bank of river, nail in root of hickory tree	697.83
35.4	Surface of water	692
36.5	Right bank, nail in root of water oak	700.62
36.5	Surface of water	694
39.4	Johnsons Bridge, east end of, top of bolt	717.53
39.4	Surface of water	702
40.2	Surface of water	705
40.3	Surface of water	707
40.8	Surface of water	709
40.9	Surface of water	711
40.9	Old dam, west side, on point in stone masonry	722.88
40.9	Surface of water	712
41.3	Foot of shoals, surface of water	714
	Head of shoals, surface of water	715
41.9	Opposite shoals, right bank, 20 feet from stream, nail in root of white oak	730.91
41.9	Surface of water	715
42.4	Mountain Creek, opposite, nail in root of white oak	727.91
42.4	Surface of water	720
43.2	Rock Bridge, on left bank, top of stone pier of	740.60
43.2	Surface of water	724
44	West bank, 10 feet from river, nail in root of ash tree	728.48
44	Surface of water	727
45.5	Opposite foot of shoals, nail in root of hickory tree	748.83
45.5	Surface of water	729
	Anniestown Shoals, foot of, surface of water	737
	Anniestown dam, foot of, surface of water	760
	Head of dam, surface of water	771
47.2	Anniestown, east bank of Haydens Branch, nail in root of large birch tree	777.64
48.6	Old mill, on large rock opposite, chisel mark	788.55

Elevations on Yellow River from mouth near Worthville to Yellow River, Ga.—Continued.

Distance in miles.		Elevation in feet.
48.6	Surface of water	772
	Head of shoals, surface of water	786
50.5	Sextons Bridge, on stone pier at, top of iron bolt	809.94
50.5	Surface of water	791
51.7	Opposite shoals, nail in root of pine	808.42
51.7	Surface of water	793
	Foot of shoals, surface of water	797
	Head of shoals, surface of water	802
53	Head of shoals, nail in root of hickory tree	818.17
53	Surface of water	804
54	Surface of water	807
55	Yellow River Bridge, left bank, nail in root of oak	825.41
55	Surface of water	815
55.7	Yellow River, east bank, 100 yardsa bove Simmons's mill, nail in root of large water oak	834.86
	Simmons's mill, below dam, surface of water	819
	Simmons's mill, head of dam, surface of water	826

ALCOVY RIVER BELOW DABNEY'S BRIDGE, GEORGIA.

In connection with this survey 17 bench marks were established and 26 water elevations were recorded. The total fall in the distance surveyed is 231 feet, but at only two points, namely, White and Factory shoals and Henderson Shoals, is the fall considerable. The remainder of the river is mostly sluggish, and tree trunks, driftwood, and other débris greatly retard the flow, so that during the rainy season the river is slow to discharge, causing the water to rise higher or spread out wider than is usually the case with rivers in this section of Georgia. The average width of the river is about 125 feet, except where shoals occur, at which points it sometimes widens to 300 feet. Very wide and low bottom lands are on each side for the first 7 miles upstream from its mouth. Then the topography suddenly changes and is much more abrupt and broken for several miles.

At the mouth of Bear Creek, which enters from the east 8 miles above the mouth of the Alcovy, is the beginning of White and Factory shoals, which form one continuous series with a fall of 83 feet in one-half mile. Here the river is in a gorge 300 feet wide, with banks over 100 feet high at several places, and midway of this shoal is an excellent site for a dam. Granite, apparently free from seams, is exposed at the surface on both sides of the river, while the river bed itself is solid rock. A dam at this point would be approxi-

mately 250 feet long. At the upper end of the shoals is another good site with the same character of bottom. A dam would have to be about 325 feet in length, and a large volume of water could be stored through the dry season, as the valley widens just above the dam site. A dam at either site would require a canal from the dam to the foot of the shoals. An old corn mill at this point uses a small wooden dam to divert the water into its flumes. Many years ago a large cotton factory stood on this site, but it was burned and never rebuilt.

Six miles above these shoals are Henderson Shoals, with a fall of 2 feet. A 6-foot dam has been erected here to supply power for a large gristmill, the back water from which extends to Dabney's bridge, 4 miles above.

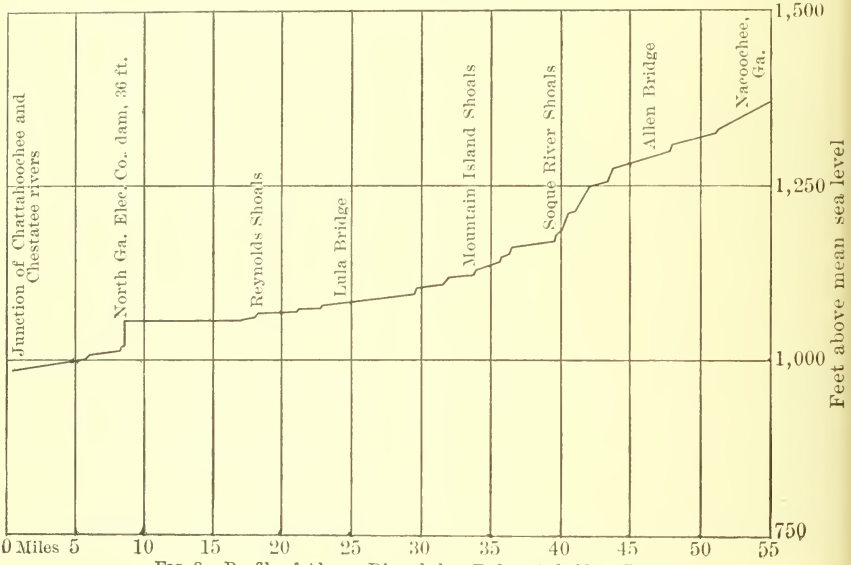


FIG. 8.—Profile of Alcovy River below Dabney's bridge, Georgia.

The construction of dams at any other points than those described would result in the sacrifice of much valuable bottom land.

The soil is very fertile, and splendid crops of cotton on the high lands and corn in the bottoms are grown on both sides of the river. With better drainage, however, a much larger amount of land could be reclaimed and made valuable for cultivation.

The elevations in the following list are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta marked "1050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level, as determined by the 1903 adjustment. The initial point of this list is a bench mark of flying levels on Ocmulgee River.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Alcovy River, from mouth, near Worthville, to Dabney's bridge, near Starrsville.

Distance in miles.		Elevation in feet.
0.0	Alcovy River, mouth of, opposite, on west bank of Ocmulgee River, nail in root of white oak	494.27
.0	Surface of water	484
1	Right bank of river, nail in root of ash tree	493.73
1	Surface of water	487
2	East bank of river, near water, nail in root of ash tree	498.40
2	Surface of water	492
3.9	Waters's bridge, spike in northeast corner	506.55
3.9	Surface of water	493
4.9	West side of river, near water, nail in root of ash tree	505.37
4.9	Surface of water	497
5.9	Left bank of river, nail in root of birch tree	505.51
5.9	Surface of water	500
6.3	Mackey Shoals, opposite foot of, on left bank, nail in root of ash tree	512.77
6.3	Mackey Shoals, foot of, surface of water	502
6.4	Mackey Shoals, head of, surface of water	504
8.2	Mackey Second Shoals, opposite foot of, left bank, nail in root of birch tree	518.50
8.2	Mackey Second Shoals, foot of, surface of water	505
	Mackey Second Shoals, head of, surface of water	508
9	Newton Factory Shoals, foot of, surface of water	509
9.2	Dam at White's mill, on Newton Factory Shoals, opposite, nail in root of black gum	562.86
9.2	Dam, foot of, surface of water	553
9.2	Dam, top of, surface of water	558
9.8	Newton Factory Bridge, on lower end of, on nut, top of bolt	592.81
9.8	Surface of water	582
10	Newton Factory Shoals, head of, surface of water	592
10.8	Left bank of river, nail in root of red-oak tree	619.86
10.8	Surface of water	593
11.5	Foot of shoals, surface of water	594
11.55	Head of shoals, surface of water	596
12.3	Left bank of river, nail in root of water oak	604.59
12.3	Surface of water	597
13	West bank, opposite shoals, nail in root of large beech tree	604.88
13	Surface of water	598
13.3	East bank river, nail in sweet-gum tree	612.85
14	Left bank river, nail in root of water oak	620.76
14	Surface of water	602
15	Henderson's bridge and mill, right bank of river, near end of bridge, nail in root of post oak	618.99
15	Surface of water	604

Elevations on Alcovy River, from mouth, near Worthville, to Dabney's bridge, near Starrsville—Continued.

Distance in miles.		Elevation in feet.
15	Henderson's mill, foot of dam, surface of water	607
15	Henderson's mill, head of dam, surface of water	613
18.3	Dabney's bridge, west side of river, near end of, nail in root of water oak (raised cut with hatchet)	627.22
18.3	Surface of water	615

TOWALIGA RIVER BELOW HIGHFALLS, GA.

Towaliga River was surveyed from its mouth, near Berner, Ga., to Highfalls, Ga., a distance of 21.7 miles. The levels are based on a line carried down South and Ocmulgee rivers from Constitution earlier in the season. The plane-table sheets were all plotted on the scale of 1:22,500. Twelve bench marks were established and 23 water-surface elevations were determined.

Towaliga River flows in a southeasterly direction and empties into Ocmulgee River. In the distance surveyed there is a fall of 194 feet, but with the exception of Highfalls there are few shoals or rapids. For 21 miles above its mouth the stream does not average more than 50 feet in width, and is very shallow. It is swift and has a clean bed.

At Highfalls there is a drop of 95 feet in a distance of 3,000 feet, in the middle of which there is a sudden drop of 42 feet, known as the Highfalls. This is an excellent dam site, for, although during the normal stage of water the volume is small, there are splendid facilities to store the water above, as the bottom is widened out into a natural basin. A flour mill has been in operation here for over one hundred years, but it uses only a trifling part of the power. It is now proposed to erect a 25-foot dam at this point to supply electric power for a railway to Indian Springs, Ga., a summer resort 8 miles from Highfalls, and also for lighting the town of Forsythe, 14 miles to the southwest. Property for 6 miles above the falls has been purchased for a storage basin. Between Highfalls and the mouth of the river there are good bottom lands, but the country is thinly settled and most of it is still in timber. The principal crops are cotton and corn.

The elevations in the following list are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta, marked "1050 M C," the elevation of which is accepted as 1,049.546 feet above mean sea level, as determined by the 1903 adjustment. The initial point of this list is a bench mark of flying levels on Ocmulgee River.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

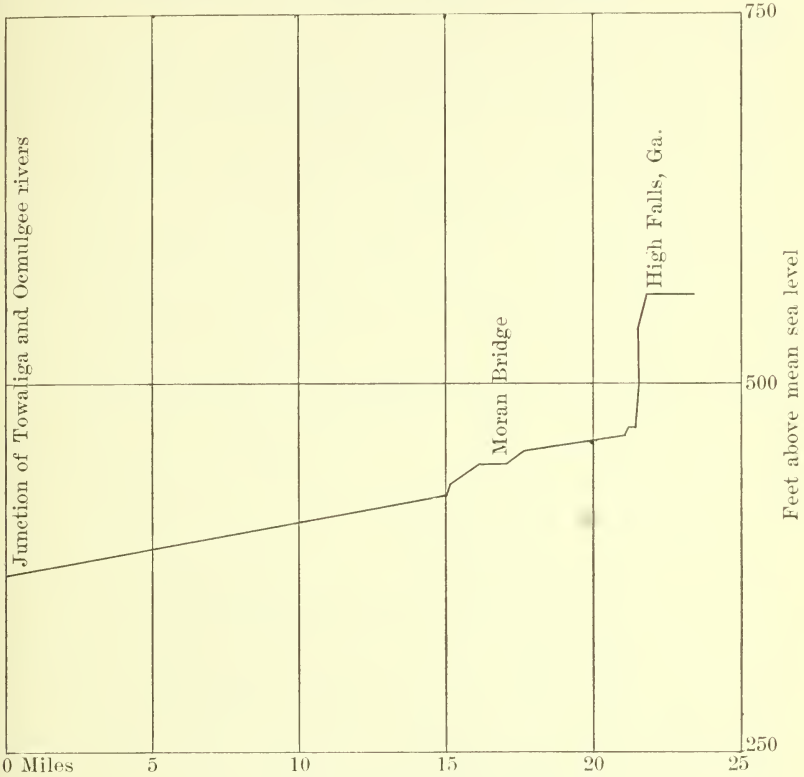


FIG. 9.—Profile of Towaliga below Highfalls, Ga.

Elevations on Towaliga River from mouth, near Berner, to Highfalls.

Distance in miles.		Elevation in feet.
0.0	Towaliga River, mouth of, on south side between railroad track and river, nail in root of water oak	379.34
.0	Surface of water	367
1.7	Lamars Bridge, near east end of, nail in root of beech tree	381.99
1.7	Surface of water	371
2.2	Small creek on west bank, mouth of, nail in root of ash tree	377.38
2.2	Surface of water	373
3.7	Surface of water	376
4	West bank, 50 feet from river, nail in root of large pine tree	412.45
4	Surface of water	379
4.6	Surface of water	382
6	Hunting Shoal Bridge, stone pier, on north end of bridge, iron bolt	412.80
6	Surface of water	386
7	North bank, 10 feet from river, twin water oak, nail in root of	399.49
7	Surface of water	393

Elevations on Towaliga River from mouth, near Berner, to Highfalls—Continued.

Distance in miles.		Elevation in feet.
8.8	Jacksons Bridge, west bank of river, large poplar tree, nail in root of	409.84
8.8	Surface of water	395
9.5	Surface of water	377
10.5	West bank of river, creek, 100 yards above mouth of, 10 feet from river, nail in root of pine tree	416.15
10.5	Surface of water	400
11.8	Wilsons Bridge, 10 feet below east approach, nail in root of water oak	421.06
11.8	Surface of water	406
12.3	West bank, on water oak	431.01
12.3	Surface of water	410
13.3	North and South forks of North Fork, 100 yards above junction of, nail in root of birch tree	416.93
13.3	Surface of water	414
14	Foot of shoals, surface of water	418
14.1	Head of shoals, surface of water	421
15	Foot of shoals, surface of water	422
15.1	Head of shoals, surface of water	428
15	Opposite shoals, north bank, nail in root of birch tree	432.23
15.5	Foot of shoals, surface of water	429
15.6	Head of shoals, surface of water	434
16	Morans Bridge, on north bank, 20 feet east of, nail in root of white oak	443.61
16	Foot of shoals, surface of water	437
16.1	Head of shoals, surface of water	439
17.4	Opposite shoals, nail in root of willow	449.74
17.4	Surface of water	443
17.5	Foot of shoals, surface of water	446
17.5	Head of shoals, surface of water	450
18	Tobes Creek, mouth of, nail in root of pine	457.48
18	Surface of water	452
18.5	Foot of shoals, surface of water	452
.0	Head of shoals, surface of water	454
18.7	Small shoals, surface of water	455
.0	Head of small shoals, surface of water	457
19.2	Branch, south bank, 20 feet above mouth of, nail in root of birch tree	462.60
21.2	Long shoals, foot of, south bank, nail in white oak tree	474.31
21.2	Surface of water	466
21.2	Highfalls Shoals, foot of, surface of water	492
21.3	Highfalls, head of Highfalls Shoals, surface of water	524
21.3	Highfalls, wagon bridge over Towiliga River, west side north approach to, top of iron bolt	563.32
21.7	Old dam, opposite, head of long shoals, surface of water	561
.0	Highfalls, high-water mark	561

CHATTAHOOCHEE RIVER FROM CHESTATEE TO SAUTEE, GA.

A survey of the upper Chattahoochee River between Chestatee and Sautee, Ga., a distance of 55 miles, was made during July and August, 1903. Between these two points a fall of 387 feet was found, the greater part of which is above the mouth of Soque River. During the survey 25 bench marks were established and 90 water-surface elevations determined. The plane-table sheets were plotted on a scale of 1:22,500. The original elevations for the levels were based upon an assumed elevation near Gainesville, Ga., but, as published herein, they have been reduced to mean sea level.

Above the mouth of Chestatee River for 10 miles are a number of small shoals aggregating a fall of 28 feet. Ten miles above the mouth of the Chestatee, Little River empties from the north, and at this point are the first good shoals, where there is a fall of 7 feet in a distance of 300 yards. A quarter of a mile above this point the North Georgia Electric Company is constructing a dam 36 feet high, which is to supply electric power. The backwater from this dam will extend 8 miles upstream, to just above Clarks Bridge. One half mile above this point is a shoal having a 9-foot fall in half a mile.

Just above this shoal are Reynolds Shoals, with a fall of 6 feet in 250 yards. There is a good power site at this point, as the banks and bottom are hard rock. From here to Mud Creek, 3 miles, there is a uniformly distributed fall of 15 feet, while just above the mouth of Mud Creek there is a good dam site. A dam here would be about 300 feet long, but the height could be 40 to 50 feet or more, if desired.

The next shoal of importance is Mountain Island Shoal. It gives a fall of 8 feet in half a mile. Here the river flows around the island between banks 100 feet high. A dam at the lower end would be 300 feet long. Perkins Shoals come next, 2 miles upstream, with a fall of 6 feet, and just above them is a shoal with a 7-foot fall. These could be used together.

From here to the mouth of Soque River is a uniform fall of 11 feet, and just above the mouth of the Soque there is a fall of 8 feet in 650 feet. For the next 3 miles there is a continuous succession of shoals, with a fall of 74 feet. The river flows in a narrow gorge of hard, unseamed rock, and at several points dams could easily be constructed. Above this point the river narrows very greatly, and is full of small shoals as far as Nacoochee Valley. From the valley to the end of the survey there are no falls or shoals.

Nacoochee Valley is very fertile and grain and grasses are raised. A large quantity of timber is still standing along the river, especially in the upper half of the valley.

The elevations in the following list are based upon an aluminum tablet at Nacoochee, marked "1349 Atlanta," in a ledge of rock 200

feet west of ford of Chattahoochee River, the elevation of which is now accepted as 1,348.269 feet above mean sea level.

The adjustment of this line was accomplished in conjunction with leveling on Chestatee and Soque rivers, tied at Willow and Clarksville, respectively, and by an extra check at Pole to primary-level circuits, and accords with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

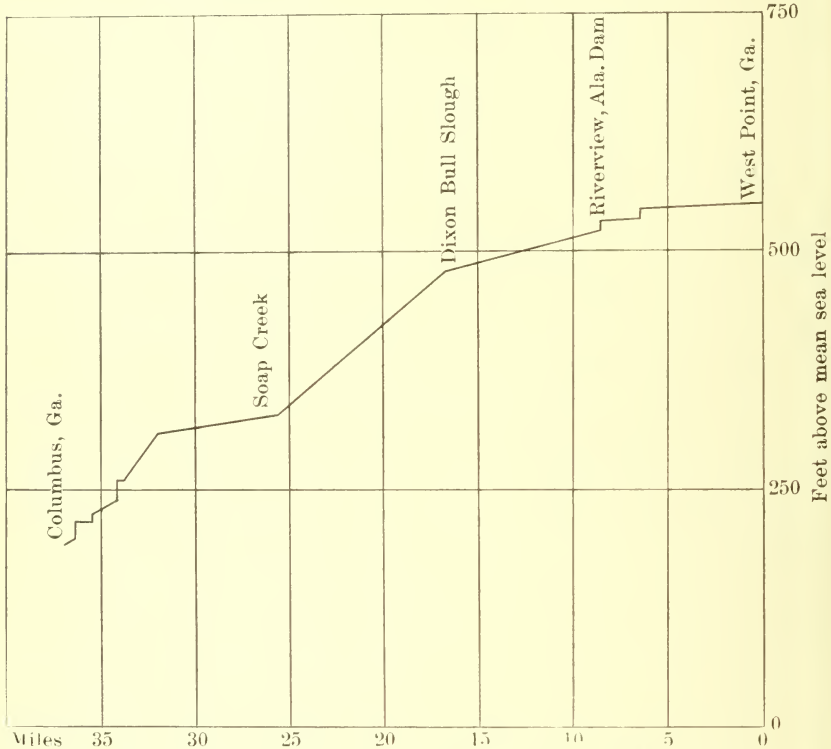


FIG. 10.—Profile of Chattahoochee River from Nacoochee to junction with Chestatee River, Ga.

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee.

Distance in miles.		Elevation in feet.
0.0	Near Keith's bridge, mouth of Chestatee River, on nail in root of walnut tree	964.37
.0	Surface of water	950
.0	Foot of shoals, surface of water	950
.0	Head of shoals, surface of water	956
1.7	On nail in root of walnut tree, north bank of river	989.71
3.7	Foot of shoals, surface of water	960
3.7	Head of shoals, surface of water	963

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
5.7	Small shoals, edge of public road opposite, nail in root of large walnut tree	985.61
5.7	Small shoals, surface of water	965
6.2	Surface of water	966
6.8	Iron bridge, nail in root of large walnut tree	980.26
6.8	Surface of water	967
6.8	Foot of shoals, surface of water	967
7.3	Head of shoals, surface of water	972
8.3	Thompson Bridge, nail in root of large walnut tree	998.36
8.3	Surface of water	977
9.4	Little River, mouth of, foot of shoals, surface of water	978
9.4	Head of shoals, surface of water	984
10	North Georgia Electric Company's new dam, 100 yards below, north side of bluff, nail in root of white oak	1,004.04
10	Surface of water	985
11	Chattahoochee Park, on east side and at sharp bend of river, nail in birch tree	1,004.27
	Foot of shoals, surface of water	996
	Head of shoals, surface of water	1,010
12.2	New Bridge, near Gainesville, near small store building, large oak tree, spike in root of	1,028.32
12.2	Surface of water	1,011
13.2	South bank of river, 6 feet from water, willow tree, nail in root of	1,014.94
13.2	Surface of water	1,012
13.9	Foot of shoals, surface of water	1,012
	Head of shoals, surface of water	1,014
16.2	Clarks Bridge, east side of river, large maple tree, nail in root of	1,039.81
16.2	Surface of water	1,017
17.2	Small bluff, north side of river, poplar tree, nail in root of	1,045.27
17.2	Surface of water	1,020
	Head of shoals, surface of water	1,024
19.2	Red oak tree, nail in root of	1,043.29
19.2	Foot of shoals, surface of water	1,025
19.5	Foot of shoals, surface of water	1,028
	Head of shoals, surface of water	1,332
21.2	Savage Ferry, nail in notch of oak post	1,051.30
21.2	Surface of water	1,034
22.2	Left bank of river, nail in root of birch tree	1,050.46
22.2	Surface of water	1,037
23.9	North bank of river, nail in root of water-oak tree	1,046.76
23.9	Surface of water	1,038

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
23.9	Head of shoals, surface of water	1,040
24.9	Seven Island shoals, opposite foot of, large poplar tree, nail in root of	1,066.94
	Foot of shoals, surface of water	1,040
	Head of shoals, surface of water	1,044
25.6	Flat Creek, 1 mile above mouth of, nail in root of poplar tree	1,045.84
25.6	Surface of water	1,045
26.5	Lulu bridge, 60 feet below, on north bank of river, red oak tree, nail in root of	1,065.68
26.5	Surface of water	1,049
28.8	Walnut tree in large open bottom, left bank of river, nail in root of	1,076.23
	Surface of water	1,053
29.8	Belton bridge, 100 yards below, right bank of river, walnut tree, nail in root of	1,076
29.8	Surface of water	1,056
31.8	Right bank of river, pine tree, nail in root of	1,092.99
31.8	Foot of shoals, surface of water	1,061
31.9	Head of shoals, surface of water	1,069
32.6	Nail in root of birch tree	1,085.79
32.6	Surface of water	1,070
	Foot of shoals, surface of water	1,071
	Head of shoals, surface of water	1,073
33.1	Head of shoals, on side of bluff, large pine, opposite, nail in root of	1,092.83
33.1	Surface of water	1,082
33.2	Harrisons Shoals, foot of, surface of water	1,084
34.1	Harrisons Shoals, opposite, nail in root of oak tree	1,101.70
34.1	Harrisons Shoals, surface of water	1,087
	Harrisons Shoals, head of, mouth of Mossy Creek, surface of water	1,087
34.2	Mountain Island Shoals, foot of, surface of water	1,088
	Head of shoals, surface of water	1,096
34.5	Head of shoals, opposite, nail in root of white oak	1,109.78
35.2	Foot of shoals, surface of water	1,101
35.2	Head of shoals, surface of water	1,106
35.2	Perkins Shoals, opposite foot of, nail in root of water oak	1,113.68
35.2	Perkins Shoals, foot of, surface of water	1,107
	Perkins Shoals, head of, surface of water	1,113
37.3	Foot of shoals, surface of water	1,115
	Head of shoals, surface of water	1,123
37.4	Head of shoals, north bank of river, opposite, nail in root of black-gum tree	1,127.76
38.2	Foot of shoals, surface of water	1,127
38.2	Head of shoals, surface of water	1,130

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
38.3	Duncan Bridge, 30 feet below, nail in red-oak tree	1,148.90
38.4	Foot of shoals, surface of water	1,131
38.6	Head of shoals, surface of water	1,135
38.6	Head of shoals, opposite, nail in root of water oak	1,155.41
39.3	Soque River, south bank, at mouth, nail in root of birch tree	1,147.82
39.3	Surface of water	1,137
39.3	Soque River, mouth of, in forks of river, nail in root of pine stump	1,148.86
39.3	Surface of water	1,137
39.6	Head of shoals, surface of water	1,144
39.8	Foot of shoals, surface of water	1,149
40	Head of shoals, surface of water	1,159
40	Head of shoals, opposite, on west bank of river, nail in root of red oak	1,165.20
40.5	Long shoals, head of, surface of water	1,178
40.8	Foot of shoals, surface of water	1,178
	Head of shoals, surface of water	1,216
41.8	Head of shoals, root of hickory tree	1,222.10
42.3	Irwins Bridge, 10 feet below, left bank of river, nail in root of poplar tree	1,223.37
42.3	Surface of water	1,216
42.6	Irwins bridge, just above, surface of water	1,222
43.2	Head of shoals, surface of water	1,228
43.5	Foot of shoals, surface of water	1,229
	Head of shoals, surface of water	1,242
43.5	Blue Creek, surface of water	1,243
43.6	Blue Creek, 100 yards above mouth of, in fork, nail in root of red oak tree	1,256.09
44.2	Amos Ford, on west bank, large birch tree, nail in root of	1,256.09
44.2	Surface of water	1,244
44.5	Surface of water	1,247
45	Head of shoals, surface of water	1,250
46	Allens Bridge, west end of, red oak tree, nail in root of	1,266.49
46	Surface of water	1,256
	Head of shoals, surface of water	1,259
46.8	Foot of shoals, surface of water	1,260
	Head of shoals, surface of water	1,263
46.8	Head of shoals, opposite, nail in root of birch tree	1,264.18
47.3	Foot of shoals, surface of water	1,271
	Head of shoals, surface of water	1,274
47.5	Shoals, opposite head of, nail in root of pine tree	1,280.73
48.5	Foot of shoals, surface of water	1,276

Elevations on Chattahoochee River from Keith's bridge, at mouth of Chestatee River, to Nacoochee—Continued.

Distance in miles.		Elevation in feet.
49	Head of shoals, surface of water	1,280
49	Shoals, red oak opposite head of, nail in root of	1,285.53
49	Head of shoals, surface of water	1,288
49.2	Sharp bend of river, water oak tree, nail in root of	1,304.53
49.2	Surface of water	1,292
50.5	Suspension footbridge, poplar tree at, nail in root of	1,305.97
50.5	Surface of water	1,297
51.8	Foot of shoals, surface of water	1,299
	Head of shoals, surface of water	1,306
53	Sautee Creek, near mouth of, in Nacoochee Valley, surface of water	1,309
55	Sautee Creek, ford near mouth, surface of water	1,339
55	Nacoochee post-office, 200 feet west of, ford of Chattahoochee River, 6 feet above surface of road, on ledge of rock, aluminum tablet marked "1349 Atlanta"	1,348.269

CHATTAHOOCHEE RIVER FROM CHATTAHOOCHEE TO FRANKLIN, GA.

A survey of the middle Chattahoochee River was made between Chattahoochee and Franklin, Ga., a distance of 65 miles. The elevations for this survey were based upon the United States Geological Survey bench mark at Chattahoochee, Ga., and the plane-table sheets were plotted on a scale of 1:22,500.

In the lower section of the river for 21 miles the Chattahoochee is without shoals or rapids until Redmens Shoals are reached, where there is a fall of 2 feet. The next shoals, Maderia Shoals, 11 miles farther downstream, have a fall of 6 feet in half a mile. Here, on the west side, is a large bluff of hard rock, and on the east side are flat bottom lands. The water is very shallow, and the stream has a rocky bottom. A dam here would be about 600 feet long, and to be made of sufficient height to develop any amount of head would flood valuable bottom lands above.

Below Maderia Shoals the river runs over small riffles of 1 to 2 feet until the Central of Georgia Railroad bridge is reached, and for 5 miles below this point there is practically no fall until McIntosh Shoals are reached, where there is a fall of 8 feet in a quarter of a mile. The river here runs through broken country, with high banks on both sides, showing good exposures of hard rock. A dam here would be 600 feet long, but several rocky islands would probably reduce the cost of construction. The dam could be 25 feet high or more if necessary.

Seven miles farther down the river are Fishtrap Shoals, with a 6-foot fall in a quarter of a mile. A dam here would be 700 feet long, as the west bank is low. Two miles downstream is the beginning of Bushhead Shoals, the best dam site on this section of the river. Here there is a fall of 7 feet, but added to the 5 feet just above and the 6 feet of Fishtrap Shoal, a total fall of 19 feet could be obtained in a distance of 5 miles. A dam built here would be 650 feet long and could be of any desired height. Good rock is exposed on each bank. Two flourishing towns, Newnan and Carrollton, which are about 15 miles from here, in opposite directions, would utilize this power. One mile below is a small 4-foot shoal, where the banks of the river are very flat.

At the mouth of Centralhatchee Creek, 2 miles below, is the last shoal, which has a 2-foot fall. It does not offer a good opportunity for development, owing to the low and extensive bottom lands on

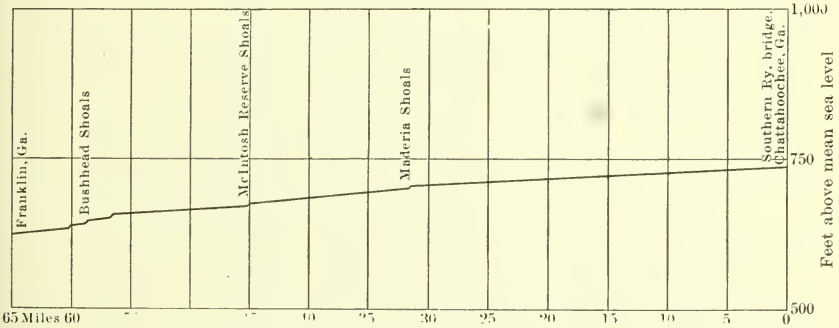


FIG. 11.—Profile of Chattahoochee River from Chattahoochee to Franklin, Ga.

the north side of the river. This section of the river has a width of about 300 feet, but in some places widens to over 1,000 feet.

Valuable and extensive bottom lands are under high cultivation, principally cotton and corn being raised, but the transportation facilities are very poor. The overflow from the river several times a year spreads a slimy sediment over the bottom which seems to act as a rich fertilizer.

For 4 miles below Chattahoochee there are valuable clay beds on the south side of the river, which have been excavated to a depth of 10 feet for brick manufacture.

The elevations in the following list are based on an aluminum tablet at the Washington street entrance to the State capitol building at Atlanta, marked "1050 M C," the elevation of which is now accepted as 1,049.546 feet above mean sea level. The line is adjusted to accord at each end, Oakdale and Franklin, with corrected primary elevations in accord with the 1903 adjustment.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Chattahoochee River from Chattahoochee to Franklin.

Distance in miles.		Elevation in feet.
0.0	Oakdale, in front of station, main track, top of south rail	809.20
.0	Surface of water	740
.5	Left bank of river, on root of willow tree	741.82
.5	Surface of water	739
1.6	Mason and Turner Ferry, near east approach to, on root to hickory tree	754.38
1.6	Surface of water	738
3.4	Old ferry, 10 feet from left bank, on root of sycamore tree	751.35
3.4	Surface of water	736
4.1	Left bank, 20 feet above bridge, on root of water oak	752.94
4.1	Surface of water	735
5.4	Left bank, 40 feet from river, on root of walnut tree	755.10
5.4	Surface of water	732
6.4	Left bank, 30 feet from river, on root of walnut tree	746.41
6.4	Surface of water	730
7.4	Left bank, 40 feet from river, on root of walnut tree	752.90
7.4	Surface of water	729
8.4	Left bank, 20 feet from river, on root of sweet gum tree	742.16
8.4	Surface of water	727
10.3	Adaholts Ferry, mouth of Sweetwater Creek, opposite, on root of large sycamore tree	744.73
10.3	Surface of water	726
11.3	Left bank, 30 feet from river, on root of large walnut tree	747.58
11.3	Surface of water	725
12.8	Dupree Ferry, left bank, 15 feet from river, on root of elm tree	738.09
12.8	Surface of water	723
14.8	Left bank, 70 feet from river, on root of walnut tree	746.29
14.8	Surface of water	721
16.6	Camp Creek, mouth of, on root of ash tree	736.13
16.6	Surface of water	720
17	Left bank, 20 feet from river, on root of walnut tree	741.78
17	Surface of water	719
17.9	Campbellton Ferry, 10 feet from river, left bank, on root of sycamore tree	728.69
17.9	Surface of water	719
20.6	Brock's ferry, 10 feet from river, left bank, on root of white oak tree	730.49
20.6	Surface of water	716
21.2	Redmens Shoals, left bank, 10 feet from river on root of sycamore tree	728.58
21.2	Surface of water	716
21.3	Redmens Shoals, foot of, surface of water	714
21.7	Pea Creek, mouth of, surface of water	714

Elevations on Chattahoochee River from Chattahoochee to Franklin—Continued.

Distance in miles.		Elevation in feet.
22	Rivertown Ferry, left bank, 10 feet from river, on root of sycamore tree	720.64
22	Surface of water	714
23.4	Pumpkintown Ferry, left bank, 15 feet from river, on large birch tree	727.94
23.4	Surface of water	712
24.5	Bear Creek, mouth of, on root of poplar tree	730.35
24.5	Surface of water	712
25.6	Left bank, 40 feet from river, on root of walnut tree	725.50
25.6	Surface of water	710
28.1	Defer's ferry, left bank, 15 feet from river, on large birch tree	722.92
28.1	Surface of water	709
29.6	Jones Ferry, left bank, 15 feet from river, on root of pine tree	718.60
29.6	Surface of water	706
30	Ballard Shoals, 10 feet from river, left bank, on root of willow tree	711.13
30.9	Ballard Shoals, head of, surface of water	705
31.1	Ballard Shoals, foot of, surface of water	704
31.4	Madeira Shoals, head of, surface of water	704
31.8	Madeira Shoals, opposite, on right bank, on root of white oak, side of rock bluff	716.81
31.8	Madeira Shoals, surface of water	702
32.1	Wolf Creek, mouth of, foot of Madeira Shoals, surface of water	698
33.4	Hutchinson's ferry, right bank, 20 feet from river, on root of maple tree	709.12
33.4	Surface of water	694
35.1	Long Island, upper end of, head of shoals, surface of water	692
35.1	Right bank, head of shoals, in root of pine tree	709.11
36	Long Island, opposite lower end of, foot of shoals, nail in root of water oak tree	703.37
36	Surface of water	689
37.5	Snake Creek, right bank, 10 feet from river, 100 yards above mouth, on root of willow tree	696.72
37.5	Surface of water	688
38.6	Moores Ferry, right bank, on root of large birch tree	702.85
38.6	Surface of water	686
39.2	Shoals, head of, surface of water	685
39.3	Shoals, foot of, surface of water	684
40.1	Central, of Georgia, Railroad bridge over river, right bank, 40 feet above bridge, on root of willow tree	692.12
40.1	Surface of water	684
40.1	Shoals, foot of, surface of water	683
40.7	Opposite right bank, nail on root of poplar tree	699.76
40.7	Surface of water	682

Elevations on Chattahoochee River from Chattahoochee to Franklin—Continued.

Distance in miles.		Elevation in feet.
41.4	Reese's ferry, right bank, on root of ash tree	693.86
41.4	Surface of water	682
41.7	Head of Shoals, surface of water	682
41.8	Foot of Shoals, surface of water	681
42.6	Fridell Shoals, head of, surface of water	680
42.7	Fridell Shoals, foot of, surface of water	679
43	Foot of bluff, right bank of river, nail in root of sweet gum tree	684.36
43.6	Hanson Shoals, head of, surface of water	678
43.9	Houston Ferry, nail in root of catalpa tree	684.02
43.9	Surface of water	677
44.9	McIntosh Reserve Shoals, head of, surface of water	676
45.4	McIntosh Reserve Shoals, foot of, right side of bank, nail in root of sweet gum tree	679.49
45.4	McIntosh Reserve Shoals, foot of, surface of water	668
46.1	Culpepper, mouth of, on root of red oak tree	678.04
46.1	Surface of water	667
49	Whooping Creek, mouth of, nail in root of birch tree	670.70
49	Surface of water	664
50	Brown's ferry, right bank, nail in root of walnut tree	661.96
50	Surface of water	662
50.7	Yellow Dirt Creek, right bank, nail in root of sweet gum tree	679.80
50.7	Surface of water	662
50.9	Yellow Dirt Creek, mouth of, surface of water	660
53.1	Hollingsworth Ferry, right bank, nail in root of water oak tree	673.31
53.1	Surface of water	658
55	Pink Creek, mouth of, surface of water	658
55.3	Right bank, on nail in root of sweet gum tree	664.97
55.3	Surface of water	658
56.3	Fishtrap Shoals, head of, surface of water	657
56.9	Fishtrap Shoals, right bank, opposite center of shoals, elm tree, nail in root of	670.26
56.9	Fishtrap Shoals, surface of water	652
57.5	Fishtrap Shoals, foot of, surface of water	648
58.5	Bushhead Shoals, opposite upper island, nail in root of birch	653.32
58.5	Bushhead Shoals, head of, surface of water	645
59	Bushhead Shoals, foot of, on side of bluff, nail in root of white oak	648.15
59	Bushhead Shoals, foot of, surface of water	638
60	Head of shoals, surface of water	638
60.2	Foot of shoals, surface of water	634
60.8	Head of shoals, surface of water	634
61	Foot of shoals, surface of water	632
62	Head of shoals, surface of water	632

Elevations on Chattahoochee River from Chattahoochee to Franklin—Continued.

Distance in miles		Elevation in feet.
62.2	Foot of shoals, surface of water	628
63.8	Centralhatchee Creek, opposite mouth of, nail in root of birch	633.49
63.8	Surface of water	628
64	Foot of shoals, surface of water	627
64.5	Franklin, wagon bridge, surface of water	626
64.7	Franklin, on rivet on top left iron pier of east approach of wagon bridge	655.17
65	Franklin, in south side of court-house, bronze tablet marked "695 A"	694.742

CHATTAHOOCHEE RIVER FROM WEST POINT TO COLUMBUS, GA.

Chattahoochee River was surveyed from West Point to Columbus, Ga., a distance of 37 miles, in which there is a fall of 361 feet. During the work 5 bench marks were established and 35 water-surface elevations obtained. The survey was plotted on the scale of 1:22,500, and was accompanied by a flying-level line based on a United States Geological Survey tablet at West Point, Ga.

For 4 miles below West Point the river is sluggish. At Langdale, Ala., there is a wing dam with 9 feet head, operating a knitting mill. The dam is loosely built of light lumber, connecting a number of small islands, and a large amount of water goes to waste.

Probably the best site for a permanent structure at Langdale is about one-half mile below the present mill, where a head of 18 feet would back water to just below West Point. A dam as proposed above would not, except in time of flood, spread the backwater beyond the present banks of the river.

Between Langdale and Riverview, where there is another knitting mill, there is a continuous network of small islands. At Riverview there is a 9-foot wing dam similar to that at Langdale, but it furnishes even less water, as the eastern channel is broader.

From Riverview to Columbus the river is one continuous shoal, and the choice of sites for dam construction rests on minor details rather than amount of power.

Some of the best sites are just below Houstons Ferry, 3¼ miles from Riverview, where a 24-foot dam would have good ledge-rock foundations for the 480 feet of river bed, while the ordinary red clay of the region appears on the banks.

Three miles farther downstream, about 1 mile below Blantons Ferry, is another site, but a dam here would flood a good deal of

bottom land. For 4 miles below here is one of the swiftest and roughest parts of the river. There is a good site at the end of the stretch, just below the Big Bull Slough, and another one-third of a mile above Bartlett's old ferry. The former could probably be developed into a valuable plant, supplying power to West Point, Lanett, Hamilton, Opelika, and a score of smaller towns, all less than 25 miles from this point. A dam probably could be built here with a head of 70 feet. The river bottom is ledge rock, with some bowlders, and the shores are of the same rock covered with more or less soil. A dam 70 feet high would back the water nearly to Mountain Oak Creek. Many of the islands in the river would be flooded. Some of them are large and cultivated to some extent. There would also be some flooding of bottom lands on both sides of the river, but no lands of pronounced value would be destroyed.

About 5¾ miles farther downstream, at what is known locally as Goats Rock, a dam very similar to the above could be constructed. The shore lines are very precipitous and ledge rock outcrops on both banks. A head of 70 feet would utilize all the available power between this point and the proposed dam 5¾ miles above.

Seven and one-half miles below is the beginning of what is known as the old Clapp factory falls. This is one of the best rapids on the river. Unfortunately, the river is exceptionally wide and the construction of a dam would be expensive. The old mill derived its power by means of a wing dam which has not been used upward of fifteen years. A dam here, backing the water up to Goat Rock and a canal carrying it to the foot of the falls, will give a total head of about 77 feet. The river bottom is ledge rock, and the shores are the same covered with several feet of soil.

One and one-fourth miles below the old Clapp factory is the dam of the Columbus Power Company. This dam has a head of 32 feet developed by a stone concrete dam, below which the tailrace has been deepened and separated from the river by a stone wall. Part of the power is utilized by the large cotton mill of the company situated on the east bank of the river. The balance is distributed about the city of Columbus.

One and one-fourth miles farther down the stream is what is called the city mill dam, with 9½ feet head. It is a wooden structure and needs constant attention, furnishing power to the city of Columbus and to a gristmill. Three-fourths of a mile below is a stone dam kept in good repair and owned by the Eagle and Phoenix Company one of the largest cotton manufacturing companies in the South. Just below this dam is the head of navigation for steamboats.

The elevations in the following list are based upon a bronze table in west abutment of Altanta and West Point Railroad bridge over Chattahoochee River at West Point. The elevation of this, a

determined by a net of primary levels, extended from Rome, Ga., a point on the precise-level net, is 573.193 feet above mean sea level, in accord with the 1903 corrected elevation of that place.

The leveling was done under the direction of I. T. Fitch, field assistant, by W. H. Sallee, levelman.

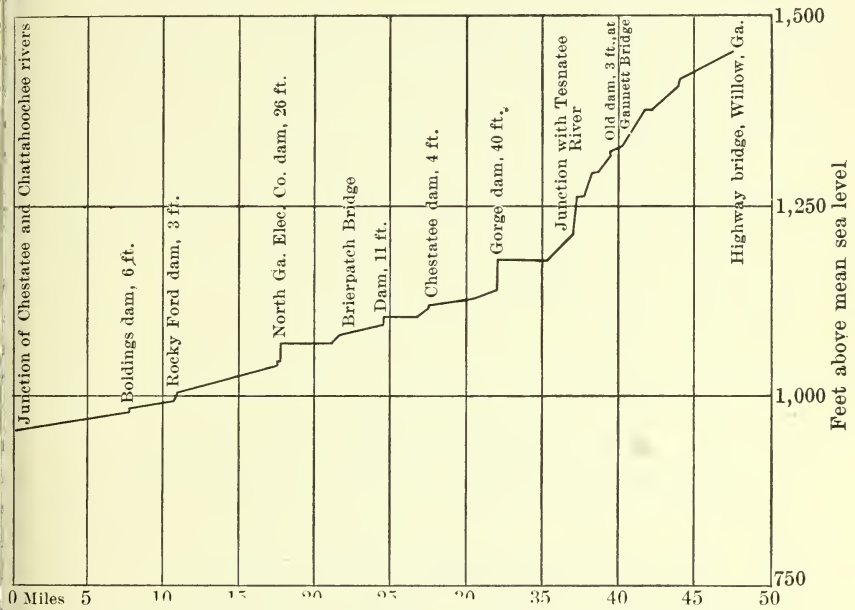


FIG. 12.—Profile of Chattahoochee River from West Point to Columbus, Ga.

Elevations on Chattahoochee River from West Point to Columbus, Ga. (single spur line)

Distance in miles.		Elevation in feet.
0.0	West Point, in west abutment of Atlanta and West Point Railroad bridge over Chattahoochee River, bronze tablet marked "573 A"	573.193
.0	Highway bridge, surface of water	551
.0	Tidewater elevation corresponding to zero of local hydrographic station	549
.0	West Point, opposite, in Alabama, United States engineers' bench mark, 1,000 feet north of highway bridge, 100 feet east of road intersection, west bank of river, 75 feet from water, iron monument sunk in ground	564.28
3.1	Long Cane Creek, surface of water	549
6	Langdale, Ala., 90 feet south of Moores Creek, in factory lawn between factory and track, top of hydrant	548.54
6	Langdale, mill pond at, surface of water	542.1
6	Langdale, below dam, surface of water	533
8.6	Riverview, mill pond, surface of water	532
8.6	Riverview, below mill pond, surface of water	522
8.6	Riverview, opposite, in Alabama, northwest corner of cotton mill, 35 feet southwest of, 50 feet south of dam, top of double-orifice hydrant	534.94

Elevations on Chattahoochee River from West Point to Columbus, Ga. (single spur line)—Continued.

Distance in miles.		Elevation in feet.
12	Houstons Ferry, surface of water	497
14.4	Blantons Ferry, west side of river, 200 feet from edge of water, 25 feet east of poplar tree, wagon road, top of knob, south side of blazed tree	508.74
16.6	Dixons Ferry, surface of water	483
20.3	Bartletts old ferry, 50 feet northwest of west bank of river, top of ledge, rock 18 feet from water	404.78
23.7	Mulberry Creek, Georgia, surface of water	363
34.7	Columbus Power Company, mill pond, surface of water	260
34.7	Columbus Power Company, below pond, surface of water	240
35.9	Columbus, mill pond of city milldam, surface of water	226
	Columbus, below mill pond of city milldam, surface of water	216
36.1	Columbus, above Eagle and Phoenix Company dam, surface of water	216
36.1	Columbus, below Eagle and Phoenix Company dam, surface of water	200
37	Columbus, beneath highway covered bridge, surface of water	190
37	Girard, Ala., Broad and Sixth streets, southeast corner of intersection, bucket and windlass well, 45 feet east of, top of stone guard post at Wm. C. Bill's saloon	255.14

SOQUE RIVER BELOW CLARKSVILLE, GA.

Soque River was surveyed from its mouth, near View, Ga., to Clarksville, Ga., a distance of 8 miles. The levels were based on a line carried up Chattahoochee River from Gainesville, Ga., and the field sheets were platted on the scale of 1:22,500.

The first power is 5½ miles above its mouth and 1 mile below from Bert. Here there is an undeveloped fall of 6 feet in about 50 yards. The south bank is hard rock; the north bank is not very high, but seems to be solid rock. The best site for a dam is probably at the lower end of the falls. A dam here would be about 380 feet long and not over 7 feet high, or the water would back up over the lower end of more valuable shoals above.

At Bert, Ga., are the Porter Shoals, which have a drop of 48 feet—far the best waterfall on the river. A small wing dam develops power to operate Porter's woolen and cotton factory, 4 miles from Demorest, Ga., the nearest railroad point.

About 500 feet upstream is Porter's upper shoal, at which there is a 15-foot fall partly developed by a small dam, and which supplies power for factory No. 2 of the same company. A much greater head would be obtained here by increasing the size of the dam.

One and one-half miles above Bert is a splendid water-power site, known as the Old Factory Shoals, where there is a fall of 23 feet in a distance of 600 feet. There was a dam here at one time, but all

signs of it have vanished. The river is about 350 feet wide and flows in several channels between small islands. Good sandstone outcrops on both banks.

Just above this point the river bottoms widen and the farming lands are better between here and Clarksville, the end of the survey, than any point on the river.

The elevations in the following list are based upon an aluminum tablet at the north side of east entrance to the court-house at Clarksville, marked "1372 Atlanta," the elevation of which is accepted as 1,371.991 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

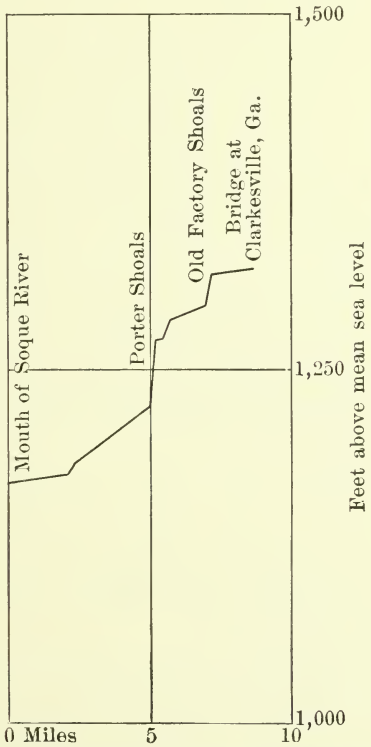


FIG. 13.—Profile of Soque River below Clarksville, Ga

Elevations on Soque River from near View to Clarksville, Ga.

Distance in miles.		Elevation in feet.
0.0	Soque River, south bank of mouth of, at junction of Soque and Chattahoochee rivers, birch tree, nail in root of	1,147.82
.0	Surface of water	1,137
1.6	McAllisters Bridge, near north end of, nail in root of white oak	1,156.30

Elevations on Soque River from near View to Clarkesville, Ga.—Continued.

Distance in miles.		Elevation in feet.
1.6	Surface of water	1,142
	Foot of shoals, surface of water	1,142
	Head of shoals, surface of water	1,149
4	Newbridge, hickory tree on north bank, nail in root	1,171.71
	Surface of water	1,152
4.1	Foot of shoals, surface of water	1,153
	Head of shoals, surface of water	1,156
4.7	Foot of shoals, surface of water	1,156
	Head of shoals, surface of water	1,162
5.6	Foot of shoals, surface of water	1,166
5.7	Head of shoals, surface of water	1,181
6.1	Porter's mills, foot of Porter Shoals, surface of water	1,189
6.1	Bert, head of Porter Shoals, surface of water	1,237
5.9	Bert, Porter Shoals, opposite head of shoals, water oak, nail in root of	1,189.07
6.1	Bert, near north end of wagon bridge, red oak tree, nail in root of	1,246.13
6.2	Bert, foot of upper shoals, surface of water	1,238
	Head of upper shoals, surface of water	1,253
6.3	Bert, Ga., 200 yards above factory, near river, on root of water oak	1,262.75
7.3	Foot of shoals, surface of water	1,261
7.3	Left bank of river, nail on root of sycamore tree	1,287.37
7.3	Surface of water, head of shoals	1,284
8.8	Clarksville, Habersham County court-house, on north side of east entrance, aluminum tablet marked "1372 Atlanta"	1,371.991
8.8	Surface of water	1,289

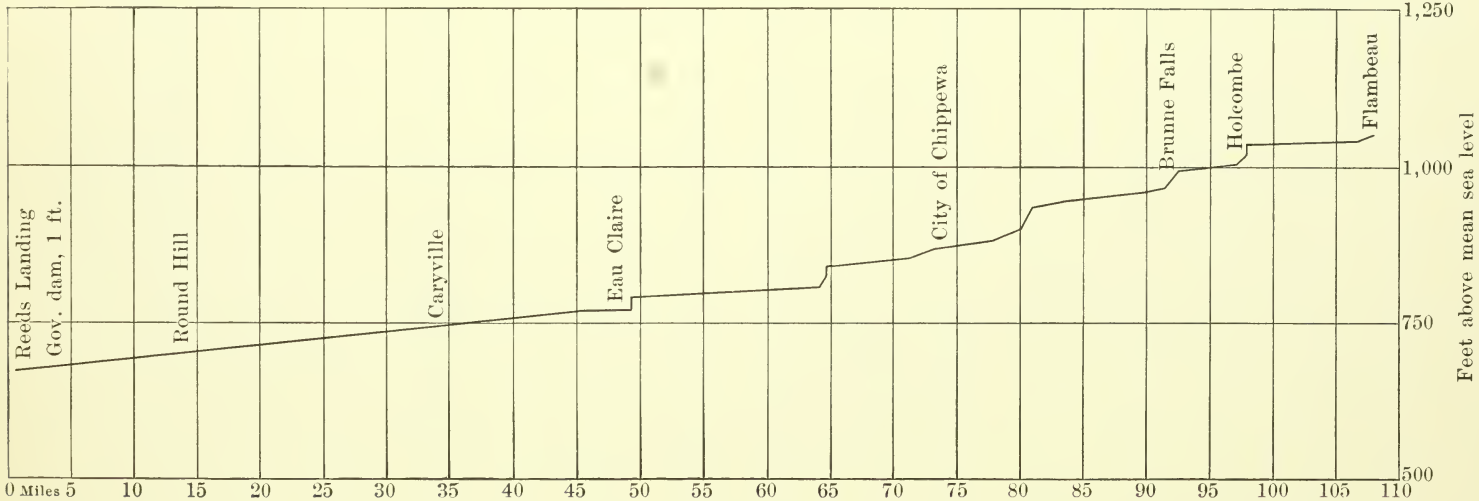
CHESTATEE RIVER BELOW WILLOW, GA.

Chestatee River was surveyed from Willow, Ga., to its mouth, near Chestatee, a distance of 47.7 miles.

A line of secondary levels was run, based on a primary bench mark of the United States Geological Survey, 2 miles north of Willow. The field sheets were platted on the scale of 1:22,500. During the course of the survey 40 bench marks were established and 98 water-surface elevations obtained.

For the first 8 miles the river traverses a very wild and broken country, and is only about 50 feet wide. There is not enough water to produce any considerable amount of power, although there is a fall of 124 feet.

At Gannett Bridge there is an old 3-foot dam which was used to furnish power for a gold-stamping mill, the machinery of which is now



PROFILE OF CHESTATEE RIVER BELOW WILLOW, GA.

ruined from disuse. This is about the north boundary of the Dahlonega gold field now under vigorous development.

One mile downstream is an unnamed shoal, with a fall of 30 feet in 0.6 of a mile. The river runs between very steep banks of hard, unseamed rocks, and a 200-foot dam could be constructed here, abundant material being easily accessible.

Just below Grinnells Ford is a splendid site, where the river suddenly drops 47 feet in about 150 yards and passes through a narrow gorge. The river bed is of broken rock, and a dam at this point would be about 200 feet long.

About 2 miles farther down is a drop of 11 feet in 100 yards. The river runs through a narrow gorge, but just above the valley widens enough to make a good storage basin. A dam would be about 225 feet long and could be built to almost any desired height. A pyrites mine here employs 50 men. Four miles below the Crown Gold Mining Company is erecting a 40-foot dam, known as the Gorge dam, to run hydraulic pumps for two placer mines.. This dam will back up the water for 2½ miles and will cover a number of small shoals.

The river below here runs swiftly, but without important shoals for about 3½ miles. It then enters the back water from Chestatee dam, which is 4 feet high, and supplies power for a gristmill, cotton gin, and hydraulic pump.

Three miles farther down is a gold-stamping mill, the power for which is supplied by an 11-foot dam, which backs the water up as far as Iron Bridge just below the Chestatee dam. Six miles farther down is a 26-foot dam, built by the North Georgia Electric Company, at Newbridge, Ga., which supplies power for the traction system and lighting of the city of Gainesville, Ga., 15 miles away. A smaller dam, 4 feet high, just below the main structure, furnishes power for a gristmill and cotton gin.

Below Newbridge, Ga., the river enters a more level country and runs with little fall to Bolden's bridge, 9 miles below, passing a 3-foot dam, which is used to operate a small flouring mill, and a 6-foot dam, which supplies power for a large gristmill.

In the remaining 8 miles there are no shoals or opportunities for power development. The sand in the bed of the river contains a large amount of gold, and placer mining on a considerable scale is one of the occupations of the people throughout this whole region.

Nearly all of the important shoals which are undeveloped are controlled by the mining interests in the neighborhood. The upper part of the survey was through fairly heavy timber, but the lower end of the work was through land all under high cultivation. The river passes 3 miles from Dahlonega, the county seat of Lumpkin County.

The elevations in the following list are based upon a bronze tablet 2.5 miles north of Willow, in rock on west side of river at fork of

road, marked "1529 Atlanta," the elevation of which is accepted as 1,528.649 feet above mean sea level, in accord with the 1903 adjustment of the precise-level net.

The leveling was done in 1903, under the direction of F. A. Franck, field assistant, by Joseph Palmer, levelman.

Elevations on Chestatee River below Willow, Ga.

Distance in miles.		Elevation in feet.
2.5	Willow, 2.5 miles north of, on west side of river, at fork of road, in rock, bronze tablet marked "1529 Atlanta"	1,528.649
.0	Willow, near west end of bridge, walnut tree, nail in root of	1,461.37
.0	Surface of water	1,454
.25	Surface of water	1,449
1	Foot of shoals, opposite, west side of river, nail in root of maple tree	1,447.54
1	Head of shoals, surface of water	1,446
	Foot of shoals, surface of water	1,444
1.6	Head of shoals, surface of water	1,443
	Foot of shoals, surface of water	1,438
2.5	Head of shoals, surface of water	1,428
2.7	Foot of shoals, surface of water	1,422
3	Right bank and 10 feet from river, nail in root of red oak tree	1,437.94
3	Surface of water	1,416
3.7	Head of large shoals, surface of water	1,415.5
3.8	Foot of large shoals, surface of water	1,406
4	Shoals, opposite, right bank of river, nail in root of red oak	1,425.41
4	Surface of water	1,405
4.2	Foot of shoals, surface of water	1,399
4.7	Sharp bend of river, right bank, nail in root of red oak	1,404.53
4.7	Surface of water	1,394
4.9	Crooked Shoal, head of, surface of water	1,390
5.2	Crooked Shoal, foot of, surface of water	1,386
5.2	Head of shoals, surface of water	1,384
5.4	Foot of shoals, surface of water	1,378
5.4	Left bank of river, opposite shoals, large white oak, nail in foot of	1,388.79
6	Head of shoals, surface of water	1,377
6.4	Foot of shoals, surface of water	1,353
6.4	Foot of shoals, left bank, 60 feet below, nail in root of hickory	1,364.25
6.9	Head of shoals, surface of water	1,346
	Foot of shoals, surface of water	1,328
7.3	Small creek, mouth of, opposite center of shoals, spruce pine, nail in root of	1,335.59
8	Old dam, top of, surface of water	1,321
	Old dam, bottom of, surface of water	1,317
8.2	Gannett Bridge, 10 feet below, on left bank river, nail in red oak	1,318.35

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
8.2	Surface of water	1,309
8.5	Old gold-stamping mill, foot of bridge at, surface of water	1,305
8.8	Head of shoals, surface of water	1,304
	Foot of shoals, surface of water	1,296
	Foot of shoals, opposite, left bank river, nail in root of sweet gum tree	1,303.10
9.4	Head of shoals, surface of water	1,293
9.9	Grinnells Ford, foot of shoals, surface of water	1,263
10	Grinnells Ford, in root of large birch tree, near ford, nail in root of	1,265.45
10.3	Head of shoals, surface of water	1,262
10.7	Tesnatee River, mouth of, foot of shoals, surface of water	1,215
10.7	Tesnatee River, mouth of, in fork between rivers, on side of rock bluff, in white oak tree, nail	1,231.37
11.1	Grinnell's lower ford, surface of water	1,209
11.2	Grinnell's lower ford, on right bank 100 yards below ford, point of large rock, chisel mark	1,218.11
11.2	Grinnell's lower ford, foot of shoals, surface of water	1,207
11.4	Head of shoals, surface of water	1,206
11.6	Foot of shoals, surface of water	1,201
11.6	Right bank of river, nail in root of hickory tree	1,214.34
11.7	Head of shoals, surface of water	1,200
11.9	Foot of shoals, surface of water	1,189
12.6	Head of shoals, surface of water	1,187
	Foot of shoals, surface of water	1,174
12.8	Right bank river, pine tree, nail in root of	1,183.54
13.5	Head of shoals, surface of water	1,169
	Foot of shoals, surface of water	1,163
14	White oak tree, nail in root of	1,166.95
14	Surface of water	1,160
14.6	Head of shoals, surface of water	1,155
	Foot of shoals, surface of water	1,150
14.9	Gorge dam, above, head of shoals, surface of water	1,149
15.8	Gorge dam, 40 feet below, right bank of river, nail in hickory tree	1,159.21
15.9	Gorge dam, below dam, foot of shoals, surface of water	1,138
16.4	Surface of water	1,133
17	Bearden's bridge, top of stone pier on west approach, iron bolt	1,150.10
17	Surface of water	1,130
17.6	Head of shoals, surface of water	1,125
17.8	Surface of water	1,122
20.2	Chestatee dam, top of, surface of water	1,119
20.2	Chestatee dam, foot of, surface of water	1,115
20.4	Iron Bridge, 60 feet below, beech tree, nail in root of	1,121.86

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
	Iron Bridge, surface of water	1,109
20.6	Foot of shoals, surface of water	1,106
	Surface of water	1,105
22.8	Gold-stamping mill, top of dam, surface of water	1,104
	Foot of dam, surface of water	1,092
	Gold-stamping mill, persimmon tree near, nail in root of	1,114.62
23.9	Branch, near mouth of, nail in root of red oak	1,106.49
23.9	Surface of water	1,089
24.2	Foot of small shoals, surface of water	1,084
25.1	Brierpatch Bridge, south side of east approach, iron bolt	1,104.71
25.1	Surface of water	1,082
26.1	Head of shoal, surface of water	1,079
26.2	Foot of shoals, surface of water	1,075
26.8	Head of shoals, surface of water	1,070
27.9	Left bank of river, pine tree, nail in root of	1,079.43
30	Georgia Electric Company's dam, top of, surface of water	1,070
	Foot of dam, surface of water	1,043
30.2	Newbridge (post-office), west side, top of central bridge pier, bolt	1,060.43
	Newbridge, head of small dam, surface of water	1,043
30.2	Small dam, foot of, surface of water	1,039
31.3	East bank, 50 feet from river, nail in root of large pine	1,062.63
31.3	Surface of water	1,028
32.5	Head of shoals, surface of water	1,027
	Foot of shoals, surface of water	1,024
32.5	Pine tree opposite shoals, nail in root of	1,049.28
33.4	Yellow Creek, 50 yards below mouth of, nail in root of red oak	1,048.27
33.4	Surface of water	1,022
33.5	Surface of water	1,017
	Head of small shoals, surface of water	1,016
	Foot of small shoals, surface of water	1,014
34.7	Robinson's ford, 10 feet from river, nail in root of red oak tree	1,025.30
	Robinson's ford, surface of water	1,012
35.7	Rock Bluff, left bank of river, nail in root of oak tree	1,020.21
35.7	Surface of water	1,009
35.8	Foot of shoals, surface of water	1,005
36.7	Flour mill, top of dam, surface of water	1,003
	Dam, foot of, surface of water	1,000
36.9	Surface of water	993
38.5	Small creek, mouth of, surface of water	986
38.8	East bank of river, 40 feet from, nail in root of red oak	1,003.69
39.6	Bolden's bridge, 40 feet from east bank, stump near bridge, nail in root of	999.56

Elevations on Chestatee River below Willow, Ga.—Continued.

Distance in miles.		Elevation in feet.
39.8	Bolden's bridge, west side of east approach, top of, iron bolt	1,001.28
39.8	Surface of water	984
39.9	Mill, top of dam, surface of water	983
	Mill, foot of dam, surface of water	977
40.8	Langleys Creek, east side, 40 feet below mouth, nail in root of red oak.	989.34
40.8	Langleys Creek, mouth of, surface of water	972
40.9	Surface of water	970
42.6	East bank of river, nail in root of sycamore tree	974.48
42.6	Surface of water	964
43.4	Surface of water	963
44.6	River, 200 feet from, in open field, nail in walnut tree	975.87
44.6	Surface of water	960
45.6	Mouth of branch, near, 40 feet from east bank of river, nail in red oak tree	981.76
47.7	Chestatee, Ga., near, at mouth of Chestatee River, near Keith's bridge, nail in root of walnut tree	964.37

HIWASSEE RIVER FROM HIWASSEE, GA., TO APALACHIA, N. C.

Hiwassee River was surveyed from Hiwassee, Ga., to Apalachia, N. C., a distance of 63 miles. In that distance there is a fall of 707 feet. A line of secondary levels based on the United States Geological Survey bench mark at Hiwassee, Ga., was run. The field sheets were plotted on the scale of 1:22,500. During the course of the survey 39 bench marks were established and 119 water-surface elevations obtained.

There are no shoals of any consequence until just below Bell Creek, where there is one of 10 feet with good rock bottom and rock bluffs on the northeast side of the river. A dam could be constructed here with a length of about 200 feet.

One mile below Hayesville Bridge is a shoal with a fall of 18 feet in 1¼ miles, but no suitable place for a dam was noted.

One and one-half miles below, at Passmore Ford, is a shoal with a 21-foot fall in 1¼ miles and with a fairly good site for the construction of a dam. The bottom is rocky and there are rock bluffs on the south side of the river. The dam would be about 300 feet long.

Four and one-half miles below is the 12-foot dam of the Cherokee Lumber Company. This is a splendid site. A 40-foot structure would not back the water over 1½ miles and would not do any damage to cultivated lands.

Three miles below, at Island Ford, is a shoal with a 17-foot fall in

1 mile. This is an excellent dam site, as the bottom is rocky and there are hard-rock bluffs on either side. The dam would be 300 feet long. Building material can be easily obtained. Five miles below, and about 1 mile above Murphy, is a shoal with a 25-foot fall in $1\frac{3}{4}$ miles. A dam about 600 feet long could be built here.

One-third mile below Murphy, at the mouth of Valley River, is the head of a shoal $1\frac{3}{4}$ miles long with a fall of 25 feet. This is an excellent power site. The bottom is rocky; both sides are of hard rock. The dam would be about 500 feet long.

Seven and one-half miles below Murphy, at Shallow Ford, is a shoal with 14-foot fall in $1\frac{1}{4}$ miles. This offers an excellent site for a dam, as bottom and banks are rocky. The dam would be about

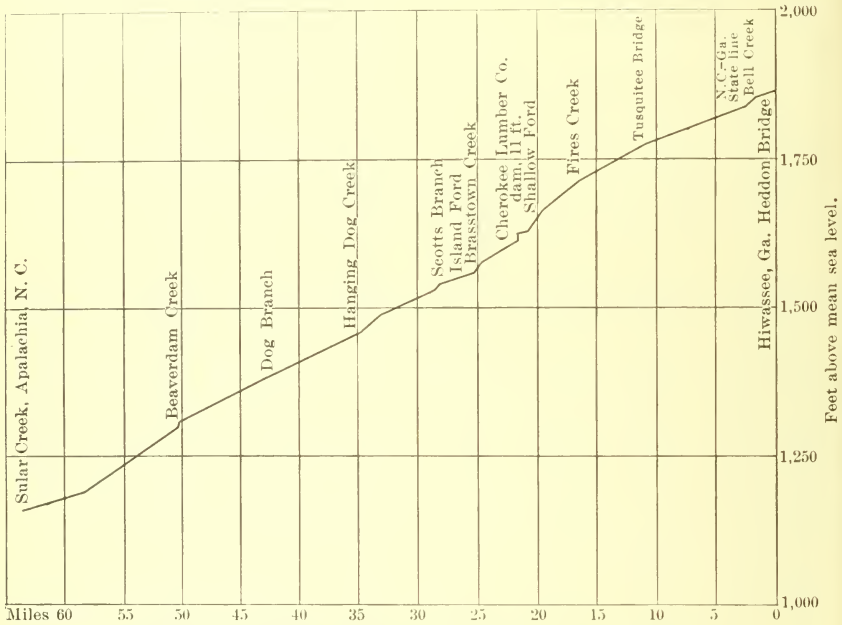


Fig. 14.—Profile of Hiwassee River from Hiwassee, Ga., to Apalachia, N. C.

550 feet long. Three miles below Shallow Ford is a shoal with a 20-foot fall in $1\frac{1}{2}$ miles. The dam here would be only about 400 feet long.

Two miles below is a 23-foot shoal $1\frac{3}{4}$ miles long, where the river runs between steep hills. The dam here would be 600 feet long. Excellent building material is at hand.

From Chambers Creek to lower Shallow Ford, $6\frac{1}{2}$ miles, the river has a fall of 15 feet per mile, and is almost a continuous shoal. There are several excellent dam sites. From Shoal Creek to Cane Creek, 2 miles, there is a shoal with a fall of 38 feet. This is a fine power site, with hard, rocky bottom and sides. A dam at this point would be about 700 feet long.

From Cane Creek down to the Tennessee State line (5 miles), the end of the survey, the river has a fall of 30 feet, with only a 7-foot shoal three-fourths of a mile between Kilpatrick Ferry and Taylor Ferry.

The elevations in the following list are based upon an aluminum tablet marked "1984 Atlanta" at the northeast corner of front vestibule of Towns County court-house, Hiwassee, Ga., the elevation of which is accepted as 1,983.634 feet above mean sea level. The leveling is adjusted with flying levels on Nottely River to accord with the 1903 adjusted elevation of primary bench mark at Blairsville and Hiwassee, Ga. From the mouth of Nottely River to Apalachia the leveling is a single spur line.

The leveling was done in 1903, under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

Elevations on Hiwassee River from Hiwassee, Ga., to Apalachia, N. C.

Distance in miles.		Elevation in feet.
0.0	Hiwassee, Towns County, court-house, at northeast corner of front vestibule, aluminum tablet marked "Atlanta, 1,984"	1,983.634
.3	Hiddon Bridge, 300 feet north of, edge of county road, white-oak tree, nail in west side of	1,882.30
.3	Hiddon Bridge, surface of water	1,865
.3	High water	1,882
.3	Bridge floor	1,881
.8	Town Branch, mouth of, surface of water	1,862
1.6	25 feet north of bridge, 20 feet west of river, point on bluff rock	1,871.36
	Bridge, surface of water	1,857
	B. F.	1,874.8
	High water	1,876
1.7	Hog Creek, mouth of, surface of water	1,855
1.9	Small rapids, surface of water	1,854
2.2	Bell Creek, 900 feet north of, on east edge of river, triple maple tree, nail in side of	1,854.14
2.2	Bell Creek, mouth of, surface of water	1,853
2.3	Small falls, head of, surface of water	1,851
2.3	Small falls, foot of, surface of water	1,847
2.8	Surface of water	1,838
3.4	Sally Ford, mouth of, surface of water	1,836
3.6	Hog Creek, mouth of, surface of water	1,833
3.7	Surface of water	1,830
3.8	Gibson Creek, mouth of, surface of water	1,829
4.8	Long Bullet Creek, mouth of, surface of water	1,825
4.8	Pendelton Ford, 25 feet northwest of, nail in side of dead stump	1,838.20
4.8	Surface of water	1,823

Elevations on Hiwassee River from Hiwassee, Ga., to Apalachia, N. C.—Continued.

Distance in miles.		Elevation in feet.
4.8	High water	1,835
5.2	Sneaking Creek, mouth of, surface of water	1,820
5.5	Surface of water	1,819
5.6	——— Ford, 75 feet northwest of, 10 feet west of road, nail in red-oak tree	1,830.62
6.1	15 feet north of river, point on rock	1,824.63
6.2	Surface of water	1,811
6.4	Stream, mouth of, surface of water	1,809
6.4	Rough Ford, 15 feet north of river, rock bluff, point on rock	1,816.84
6.9	Surface of water	1,807
7.2	Shooting Creek, mouth of, surface of water	1,804
7.9	Barnard Bridge, northeast abutment, point on top of	1,818.31
	Surface of water	1,797
	Bridge floor	1,819.7
	High water	1,814
8.3	——— Ford, surface of water	1,794
8.3	——— Ford, 50 feet south of ford, 15 feet north of river, nail in side of dogwood tree	1,807.89
8.8	Surface of water	1,790
9	Head of island	1,789
9.2	Hyatts Mill Creek, mouth of, surface of water	1,787
9.4	Herbert Ford, on south edge of river at, nail in side of birch tree	1,791.19
	High water	1,799
	Surface of water	1,787
	Blair Creek, mouth of, surface of water	1,787
10	12 feet west of river, point on rock	1,796.74
10	Surface of water	1,782
10.8	Town Creek, mouth of, surface of water	1,778
11.5	Tusquite Bridge, 250 feet west of, on edge of river, nail in root of birch tree	1,778.90
	Bridge, surface of water	1,774
	High water	1,794
11.8	Martin or Quail Creek, mouth of, surface of water	1,174
12.2	Surface of water	1,773
12.6	Tusquitee Creek, mouth of, 150 feet northwest of, 10 feet west of river, nail in root of birch tree	1,777.93
12.6	Surface of water	1,771
12.8	Rapids, surface of water	1,767
13.3	Below rapids, surface of water	1,760
13.6	Stream, mouth of, surface of water	1,759
14	Martin Ford, 125 feet south of, on west edge of river, a fish trap, nail in root of birch tree	1,757.74
	Surface of water	1,756

Elevations on Hiwassee River from Hiwassee, Ga., to Apalachia, N. C.—Continued.

Distance in miles.		Elevation in feet.
14.8	Surface of water	1,742
14.9	Leatherwood Ford, 25 feet northwest of, nail in walnut tree	1,749.19
	Surface of water	1,741
16	Allbon Creek, mouth of, surface of water	1,741
16.4	Surface of water	1,722
17	Fires Creek, mouth of, surface of water	1,712
17.3	Mountain stream, mouth of, surface of water	1,708
17.5	Passmore Ford, east side of river, in center of ford road, nail in root of gum tree	1,709.84
17.5	Surface of water	1,707
17.7	Cloud Fire Creek, mouth of, surface of water	1,700
18.3	Surface of water	1,690
18.8	Betty Creek, mouth of, surface of water	1,685
19.1	Head of island, surface of water	1,679
19.4	Sweetwater Creek, mouth of, surface of water	1,673
19.6	Stream, mouth of, surface of water	1,668
20	Shallow Ford, 15 feet east of river, nail in side of birch tree	1,667.14
20	Surface of water	1,663
20.5	Surface of water	1,659
20.9	End of island, surface of water	1,649
21	Creek, mouth of, surface of water	1,642
21.4	Surface of water	1,632
21.5	Surface of water	1,629
21.8	Backwater of Cherokee dam, 1,500 feet from, at small rapids, surface of water	1,624
22	Top of Cherokee dam, surface of water	1,625
22	Foot of dam, surface of water	1,614
22	Cherokee dam, 25 feet southwest of, point of rock	1,616.59
22	Surface of water	1,609
22.2	Canewater Ford, surface of water	1,606
24	Rocky Branch, mouth of, surface of water	1,591.4
24	North edge of river, nail in side of birch tree	1,594.79
24.1	Small rapids, foot of, surface of water	1,590
24.7	Stream, mouth of, surface of water	1,586
25.2	Brasstown Creek, mouth of, surface of water	1,576
26.2	Island Ford, 700 feet east of, south side of river, point on rock	1,566.56
27.6	Peachtree Creek, mouth of, surface of water	1,550
28	Horseshoe Ford, surface of water	1,549
28	South side of ford, nail in side of beech tree	1,553.06
29.5	20 feet north of river, north side of road, point on rock	1,548.70
29.9	Scott Branch, mouth of, surface of water	1,539
30.4	Stream, mouth of, surface of water	1,529

Elevations on Hiwassee River from Hiwasee, Ga., to Apalachia, N. C.—Continued.

Distance in miles.		Elevation in feet.
31.3	Martin Creek, mouth of, surface of water	1,520
31.6	Twin beech tree, nail in root of	1,518.12
31.8	Stream, mouth of, surface of water	1,513
32.1	Murphy, N. C., iron bridge, south abutment, point on rock	1,518.30
32.1	Surface of water	1,512
32.1	Bridge floor	1,531.9
32.1	High water	1,529
32.5	Valley River, mouth of, west shore, 20 feet north of, in water, point on rock	1,506.85
32.5	Surface of water	1,506
33.6	Surface of water	1,499
34	Surface of water	1,491
34.9	Laurel Creek, mouth of, surface of water	1,474
35.3	Johnson Ford, 8 feet south of river, nail in root of birch tree	1,471.95
35.3	Surface of water	1,469
35.3	High water	1,481
35.9	Hanging Dog Creek, mouth of, surface of water	1,462
36.5	Surface of water	1,459
37	Nottely River, mouth of, surface of water	1,455
37	On land projecting between the two rivers, birch tree, nail in root of	1,459.40
37	Nottely River, mouth of, south side of, willow tree, nail in root of	1,456.93
38	Small rapids, surface of water	1,448
39	Beach Creek, mouth of, surface of water	1,438
40.5	Surface of water	1,425
40.5	Shallow Ford, 40 feet southwest of ford, honey-bee tree, nail in root of	1,431.59
41.2	Surface of water	1,418
42	Grape Creek, mouth of, surface of water	1,416
42.5	Small shoals, head of, surface of water	1,415
42.5	Small shoals, surface of water, foot of	1,410
42.9	Surface of water	1,406
44.1	Persimmon Creek, mouth of, surface of water	1,391
44.8	Foot of large shoals, point on rock	1,390.24
44.8	Surface of water	1,381
45	Head of small shoals, surface of water	1,379
46.2	Dennest Creek, mouth of, surface of water	1,365
46.9	Point on rock	1,363.58
48	Shoals, surface of water	1,346
48.8	Robertson Ferry, 100 feet below, point on rock	1,344.23
48.8	Surface of water	1,343
49.9	Shoals, surface of water	1,340
50.4	Creek, mouth of, surface of water	1,332

Elevations on Hiwassee River from Hiwassee, Ga., to Apalachia, N. C.—Continued.

Distance in miles.		Elevation in feet.
50.6	Surface of water	1,329
51.2	Chambers Creek, mouth of, surface of water	1,324
51.2	20 feet north of bank, point on rock	1,327.94
51.8	Opposite island, surface of water	1,318
52.5	Beaverdam Creek, mouth of, surface of water	1,304
53	Opposite island, surface of water	1,296
53.9	Lared Creek, mouth of, surface of water	1,290
54.3	Shoals, surface of water	1,285
54.3	Foot of shoals, surface of water	1,277
54.8	Surface of water	1,269
55.2	Rapids, surface of water	1,259
56.9	Anderson Creek, mouth of, surface of water	1,248
57.9	Surface of water (15 feet above low water)	1,240
58.5	Shallow Ford, 40 feet south of, nail in root of gum	1,239.67
58.5	Surface of water	1,234
58.5	High water	1,241
58.6	Foot of small shoals, surface of water	1,227
58.9	Shoals Creek, mouth of, surface of water	1,227
59.7	Foot of small rapids, surface of water	1,218
60.8	Stream, south of, surface of water	1,198
61.1	Cane Creek, mouth of, surface of water	1,195
63	Surface of water	1,178
64.2	Camp Creek, mouth of, surface of water	1,175
65	Kilpatrick Ferry, 12 feet south of, willow tree	1,175.14
65	Surface of water	1,172
65.2	Taylor Ferry, 60 feet northwest of, edge of bank, point on large rock	1,169.58
65.2	Surface of water	1,166
66.8	Apalachia, N. C., Sular Creek, mouth of, 100 feet from post-office, 5 feet feet north of bank of river, triple willow tree	1,161.58
66.8	Surface of water	1,158
66.8	High water	1,168

NOTTELY RIVER BELOW BLAIRSVILLE, GA.

Nottely River was surveyed from its mouth, 3½ miles below Murphy, N. C., to Blairsville Bridge, near Blairsville, Ga., a distance of 38 miles. In that distance there is a fall of 314 feet. A line of secondary levels was run, based on a primary bench mark of the United States Geological Survey at Hiwassee, Ga., and the field sheets were plotted on a scale of 1:22,500. During the course of the

survey 30 bench marks were established and 88 water-surface elevations obtained.

One mile above the mouth of the river is a 24-foot shoal 1 mile long, where there is an excellent solid rock dam site. At this place a dam would be 200 feet long. Three and one-fourth miles farther up, at Hall Ford, there is a shoal with a fall of 33 feet in $1\frac{3}{4}$ miles, with good bottom and good sides. A dam would be about 350 feet long.

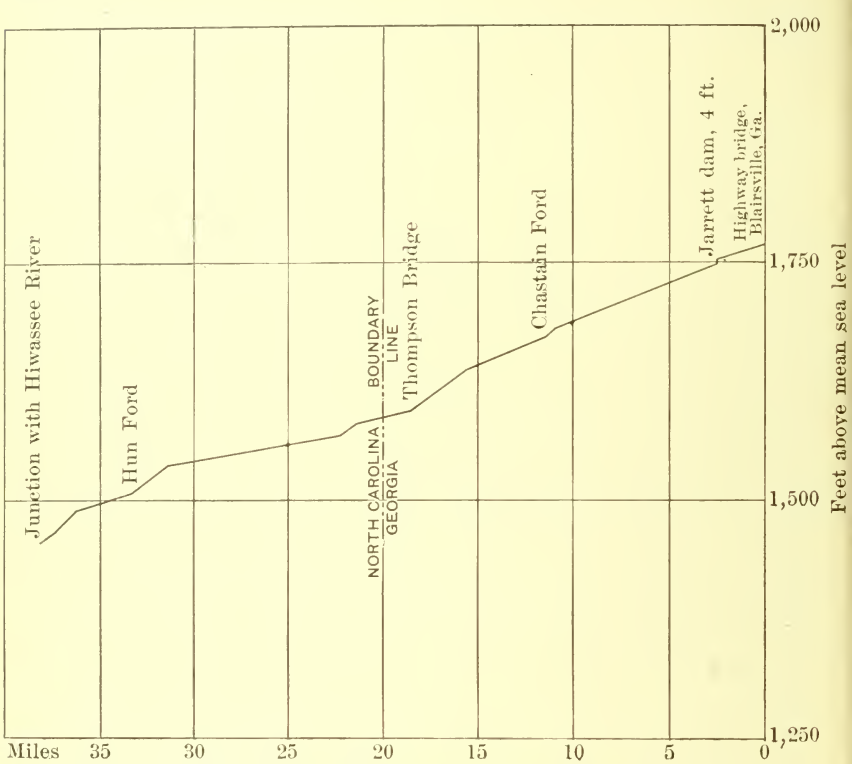


FIG. 15.—Profile of Nottely River below Blairsville, Ga.

For 9 miles above this point the bottoms widen and are cultivated on either side for most of the distance. The fall in this section is a little over 3 feet per mile.

One mile below Laudermilk Ford there is a shoal with a fall of 10 feet in three-fourths of a mile where a dam, with a length of 200 feet, could be built.

At Thompson Bridge, at the foot of a 46-foot shoal, 3 miles long, is an excellent dam site. From Weazel Creek to Morgan Ford, $5\frac{1}{2}$ miles, the river has a fall of 40 feet, and there are two or three suitable sites for small dams. At Watkins Bridge there is a 4-foot dam using all the available power to operate a gristmill.

From here to Blairsville Bridge, the end of the survey, the river is very much smaller, with a few small shoals, which, however, do not seem worth developing.

The elevations in the following list are based upon a bronze tablet marked "1892 Atlanta" in the foundation wall at northwest corner of Union County court-house, Blairsville, Ga., the elevation of which is accepted as 1,891.536 feet above mean sea level. The leveling is adjusted with the Hiwassee River flying levels to accord with the 1903 adjusted elevation of primary bench marks at Blairsville and Hiwassee.

The leveling was done, under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

Elevations on Nottely River from its mouth to Blairsville, Ga.

Distance in miles.		Elevation in feet.
0.0	Junction of Nottely and Hiwassee rivers, on point of peninsular, nail in side of birch tree	1,459.40
.0	Surface of water	1,454.52
.3	At lower ford, surface of water	1,459
.3	Seventy-five feet north of lower ford, nail in root of hickory tree	1,466.77
1	High-water mark	1,471
1	Upper ford, 50 feet south of, nail in root of oak tree	1,474.59
1	Surface of water	1,467
1.3	Surface of water	1,477
1.5	Surface of water	1,472
1.5	Surface of water	1,478
1.8	Deep Ford, 25 feet north of, nail in root of black oak	1,487.56
1.8	Surface of water	1,483
2	Surface of water	1,489
2.3	High water	1,499
2.4	Head of shoals, surface of water	1,491
2.6	Surface of water, rain during night raised 1.3 feet (lower water surface, 1,492.67 feet)	1,493
2.9	Hall Bridge, 20 feet west of, nail in side of apple tree	1,500.20
2.9	Surface of water	1,493
2.9	High water	1,503
4.2	Davis Ford, 20 feet northwest of, nail in side of maple tree	1,504.43
4.2	Surface of water	1,499
4.9	Surface of water, on rock	1,502
5.2	Mouth of Coombs Creek, surface of water	1,505
5.4	Surface of water	1,505
5.5	Hall Ford, north edge of river, nail in side of water birch tree	1,513.02
5.5	Surface of water	1,505
5.5	High water	1,521

Elevations on Nottely River from its mouth to Blairsville, Ga.—Continued.

Distance in miles.		Elevation in feet.
5.9	Mouth of branch, surface of water	1,512
6	Surface of water	1,520
6.6	Surface of water	1,526
6.9	Opposite island, surface of water	1,534
7	Mouth of Rocky Branch, surface of water	1,535
7.1	Near old mill, surface of water	1,538
7.5	Surface of water	1,542
8.6	Nottely Bridge, 1,800 feet north of, in old field near barn, nail in side of persimmon tree	1,559.54
8.6	Mouth of branch, surface of water	1,544
8.9	Nottely Bridge, 100 feet west of, 5 feet south of road, nail in side of black oak tree	1,560.13
8.9	Surface of water	1,544
9.6	Surface of water	1,547
10.5	Mouth of Johnson Branch, surface of water	1,548
10.9	Surface of water	1,551
11.5	Jack Creek, 900 feet south of, in bend of river, 600 feet west and 600 feet north of, in cornfield, nail in root of dead peach tree	1,571.83
11.5	Surface of water	1,554
11.7	Surface of water	1,555
12	Anderson Bridge, 50 feet west of, nail in side of sycamore tree	1,565.78
12	Surface of water	1,556
12	High water	1,575
12.2	Surface of water	1,560
12.9	Mouth of branch, surface of water	1,561
13.3	Ford (has no name), 20 feet northeast of, nail in side of birch stump	1,574.02
13.3	Surface of water	1,562
13.3	High water	1,577
14.2	Surface of water	1,565
15.1	Surface of water	1,568
15.4	Laudermilk Ford, 1.4 miles below, opposite old fish dam. 50 feet west of river, near small branch, nail in root of black oak tree	1,586.77
15.6	Surface of water	1,573
16	Surface of water	1,580
16.8	Laudermilk Ford, 100 feet southwest of, 20 feet north of road, nail in root of apple tree	1,598.19
16.8	Surface of water	1,583
16.8	High water	1,599
17.2	Mouth of Butler Creek, surface of water	1,585
17.7	Below fish dam, surface of water	1,587
17.8	Mouth of Moccasin Creek, surface of water	1,588
17.8	Moccasin Creek, 200 feet south of, 35 feet east of river, east side of road, nail in root of red oak tree	1,602.87

Elevations on Nottely River from its mouth to Blairsville, Ga.—Continued.

Distance in miles.		Elevation in feet.
18.5	Mouth of branch, surface of water	1,591
18.6	Mouth of Dooley Creek, surface of water	1,591
18.9	Thompson Bridge, 250 feet south of, 100 feet southeast of road, nail in root of red-oak tree	1,611.01
18.9	Surface of water	1,592
18.9	High water	1,601.53
19.1	Surface of water	1,599
19.6	In shoals, surface of water	1,611
20.2	Above fish dam, surface of water	1,617
20.4	Head of fish dam, surface of water	1,619
20.8	Foot of island, in shoals, surface of water	1,624
21	Surface of water	1,630
21.4	Chapman Ford, 150 feet north of, 2 feet east of road, nail in root of walnut tree	1,645.81
21.4	Surface of water	1,634
21.4	High water	1,644
21.8	Just below fish dam, surface of water	1,638
21.9	Mouth of Camp Creek, surface of water	1,639
22.6	Above shoals, surface of water	1,652
23	Mouth of Weasel Creek, surface of water	1,655
23.6	Mouth of branch, surface of water	1,656
23.8	In shoals, surface of water	1,657
23.8	Chamber Ford, 0.4 mile northeast of, northwest side of river, point on edge of rock	1,675.88
24.2	Chamber Ford, 200 feet west of, nail in root of walnut tree	1,671.49
24.2	Surface of water	1,661
24.2	High water	1,678
25	Above small shoals, surface of water	1,669
25.2	Chastain Ford, 50 feet west of, nail in side of walnut tree	1,683.45
25.2	Surface of water	1,669
25.5	Foot of large shoals, surface of water	1,675
25.8	Mouth of Ivylog Creek, head of shoals, surface of water	1,680
26.3	Near house, surface of water	1,685
26.6	Majners Ford, 75 feet west of, on edge of bank, nail in side of corn-bean tree	1,690.8
26.6	Surface of water	1,687
26.8	Meadow Ford, 15 feet north of, nail in root of beech tree	1,699.17
26.8	Surface of water	1,689
26.8	High water	1,703
27.3	Huggins Ford, 25 feet north of, corn bean tree, nail in side of	1,707.82
27.3	Surface of water	1,692
27.5	Shoals, surface of water	1,694
27.8	Surface of water	1,698

Elevations on Nottely River from its mouth to Blairsville, Ga.—Continued.

Distance in miles.		Elevation in feet.
27.9	Above shoals, surface of water	1,698
28.4	Morgan Ford, 40 feet north of, red-oak tree	1,714
28.4	Surface of water	1,702
29	Mouth of Young Cane Creek, surface of water	1,699
29	Mouth of Castile Creek, surface of water	1,709
29.1	Castile Creek, 1,600 feet above, on rock, edge of river, point on rock	1,714.20
29.4	Above rapids, surface of water	1,715
30	Above fish dam, surface of water	1,718
30.3	McBee Ford, 60 feet north of, nail in side of red oak	1,734.37
30.3	Surface of water	1,721
30.8	Above branch, surface of water	1,723
31.1	Mouth of Reece Creek, surface of water	1,724
31.4	Youngs Ford, 80 feet southwest of, red-oak tree	1,741.02
31.4	Surface of water	1,727
31.5	Millburn Creek, just below, surface of water	1,730
31.9	At canal, surface of water at foot of	1,732
31.9	Head of canal, surface of water	1,735
31.9	Canal cut, 50 feet northeast of river, 15 feet southwest of ford, nail in root of red-oak tree (cut has a drop of 3.6 feet)	1,741.26
32.2	Above small rapids, surface of water	1,739
33	Mouth of creek, surface of water	1,743
33.6	Watkins Bridge, 375 feet above, north edge of river, point on rock	1,747.54
33.6	Surface of water	1,747
33.6	Jarrett milldam, foot of, surface of water	1,748
33.6	Jarrett milldam, head of, surface of water (Jarrett milldam has a drop of 3.79 feet)	1,752
34.5	Reeds Ford, 150 feet east of, nail in root of walnut tree	1,766.24
34.5	Surface of water	1,755
35	Above small rapids, surface of water	1,760
35.9	Blairsville Bridge, 100 feet southeast of, mouth of Butternut Creek, 15 feet north of, nail in side of red-oak tree	1,775.94
35.9	Surface of water	1,769
35.9	High water	1,783
37.2	Blairsville court-house, Union County, Ga., in wall on west side of building, bronze tablet	1,891.536

TOCCOA RIVER BELOW DIAL, GA.

Toccoa River was surveyed from Butts Bridge, 3 miles east of Dial Ga., to the Tennessee State line, near McCays, Tenn. In the 36 miles surveyed there is a fall of 414 feet. A line of secondary levels was run, based on the primary bench mark of the United States Geological

Survey, three-fourths of a mile northeast of Butts Bridge. The field sheets were plotted on the scale of 1:22,500, and during the course of this survey 27 bench marks were established and 94 water-surface elevations were obtained.

Toccoa River flows in a northwesterly direction, and after crossing the Tennessee State line is known as Ocoee River. Between Pigeon Creek and Dial Bridge there is a shoal, with a fall of 21 feet in 1¼ miles. There are good foundations for a dam 250 feet long.

From upper Big Creek to Shallow Ford, 3 miles, there is a fall of 55 feet in an almost continuous shoal. There are several available power sites, and building material is easily accessible. From Shallow Ford

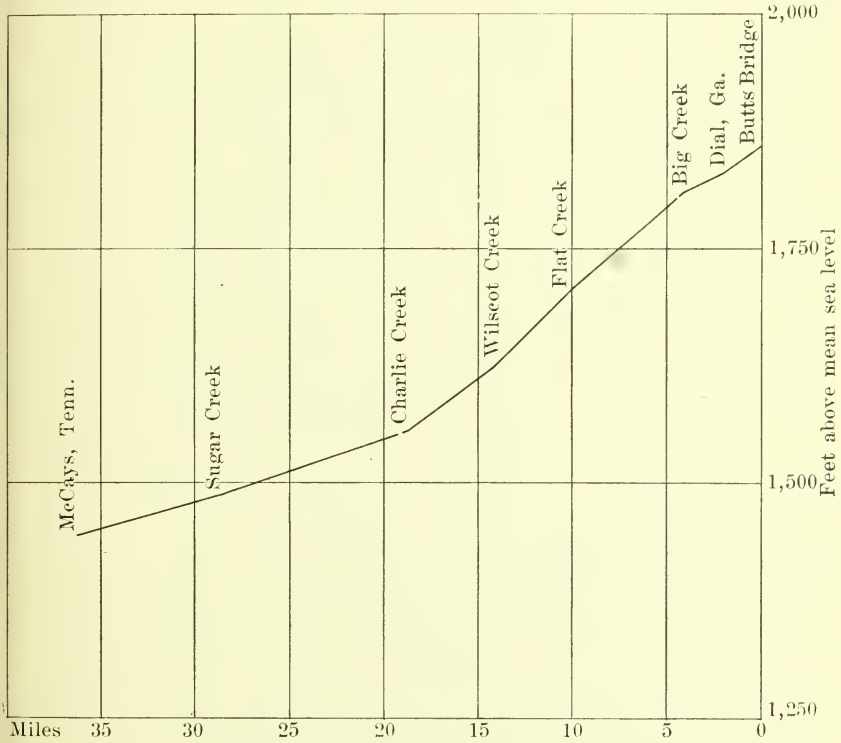


FIG. 16.—Profile of Toccoa River below Dial, Ga.

to Wilscot Creek, 7½ miles, the river has an average fall of 18 feet per mile. There are several excellent sites where there is hard rock on either side.

From Wilscot Creek to Charlie Creek there is an average fall of 14 feet per mile, with several fine shoals having steep hills and good hard bottom.

Eleven miles down the river, at Galloway, Ga., there is a shoal with a fall of 10 feet in half a mile. This would be a good site for a small dam. From one-half mile below Galloway to McCays, Tenn., 6 miles, the river has a fall of 60 feet, with several good power sites.

The elevations in the following list are based upon an aluminum tablet at the Washington street entrance of the State capitol building at Atlanta, marked "1050 M C," the elevation of which is now accepted as 1,049.546 feet above mean sea level. They accord with the 1903 adjusted elevations of primary bench marks near Morganton and Shallow Ford. The section from Shallow Ford to McCays Ferry is a single spur line.

The leveling was done under the direction of Carroll Caldwell, field assistant, by T. B. O'Hagan, levelman.

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line.

Distance in miles.		Elevation in feet.
0.0	Morganton (3 miles east of Dial), forks of Morganton and Ellijay road, in large marble rock, copper bolt marked "1981"	1,947.821
1.5	Butts Bridge, surface of water	1,858
1.5	Butts Bridge, east side of, nail in top of abutment	1,874.25
1.5	High-water mark	1,870
2	Pigeon Creek, 550 feet east of, north side of road, 60 feet north of river, point on rock	1,858.35
2	Mouth of Pigeon Creek, surface of water	1,849
2.3	Between rapids, surface of water	1,845
2.5	Foot of shoals, surface of water	1,840
2.9	Mouth of Weeks Creek, foot of rapids, surface of water	1,830
3.1	Dial post-office, Van Zant's bridge, 100 feet north of, east side of road, nail in root of red-oak tree	1,844.68
3.1	Surface of water	1,828
3.1	High-water mark	1,851
4	Mouth of Noontootly Creek, surface of water	1,823
4	Mouth of branch, surface of water	1,821
4.2	Rogers Ford, 50 feet west of, nail in root of tree	1,825.14
4.2	Surface of water	1,820
4.7	Surface of water	1,815
5.1	In rapids, surface of water	1,813
5.2	Big Creek Ford, 225 feet southeast of, 50 feet south of river, nail in root of white-oak tree	1,817.74
5.2	Surface of water	1,810
5.2	In rapids, surface of water	1,809
5.7	Above rapids, surface of water	1,802
5.9	Below fish dam, surface of water	1,799
6.1	Head of shoals, surface of water	1,795
6.4	Foot of shoals, surface of water	1,791
6.4	Surface of water	1,790
7	Surface of water	1,782
7.1	Shallow Ford, 1 mile north of, north side of road, in large rock, copper bolt marked "1859"	1,826.439

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line—Continued.

Distance in miles.		Elevation in feet.
	Single flying level spur line to McCays Ferry.	
7.1	Below rapids, surface of water	1,779
7.6	In rapids, surface of water	1,769
8.1	Shallow Ford, 100 feet north of, nail in root of red-oak tree	1,774.93
8.1	Surface of water	1,763
8.1	High-water mark	1,774
8.3	In rapids, surface of water	1,758
8.6	Surface of water	1,755
8.8	Mouth of Stanley Creek, surface of water	1,752
9.1	Rapids, surface of water	1,747
9.3	Mouth of stream, surface of water	1,743
9.5	Below rapids, surface of water	1,738
9.9	Stanley Creek, 1 mile northwest of, opposite island, north side of river, point on rock	1,738.77
10	In rapids, surface of water	1,729
10.2	Opposite falls in river, 50 feet north of first falls, point on large rock	1,744.02
10.2	Head of falls, surface of water	1,728
10.2	Foot of falls, surface of water	1,719
10.7	Mouth of branch, surface of water	1,717
11	Below rapids, surface of water	1,709
11.2	Mouth of Flat Creek, surface of water	1,705
11.5	In rapids, surface of water	1,691
11.6	Surface of water	1,690
11.8	Head of long shoals, surface of water	1,689
11.8	Rock cliff, south side of river, opposite large shoals, point in side of	1,692.11
11.9	Head of island, in shoals, surface of water	1,679
12	Foot of island, in shoals, surface of water	1,677
12.9	In shoals, surface of water	1,665
13.3	Foot of large shoals, surface of water	1,659
13.4	Below rapids, head of more shoals, surface of water	1,656
13.4	In rapids, surface of water	1,646
14	Foot of shoals, surface of water	1,640
14.6	Mouth of Persimmon Creek, surface of water	1,633
14.6	Persimmon Creek, 300 feet east of, west side of river, nail in root of large dead stump	1,638.06
14.7	Below fish dam, surface of water	1,629
15.2	Mouth of stream, surface of water	1,624
15.4	Mouth of Wilscot Creek, surface of water	1,624
15.8	In shoals, surface of water	1,616
16	Foot of shoals, surface of water	1,609
16.8	In rapids, surface of water	1,602

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line—Continued.

Distance in miles.		Elevation in feet.
	Single flying level spur line to McCays Ferry—Continued.	
8	Wilscot Creek, 1.5 miles northwest of, rock cliff, 18 feet north of river, point on very large rock	1,608.96
16.9	In shoals, surface of water	1,600
17.1	Foot of shoals, surface of water	1,596
17.3	Tarpley Ford, surface of water	1,593
17.3	Tarpley Ford, 20 feet west of, nail in root of beech tree	1,598.30
17.6	In rapids, surface of water	1,589
18.2	Mouth of creek, surface of water	1,576
18.3	Surface of water	1,571
18.8	Mouth of creek, surface of water	1,568
19	Mouth of Bullfrog Creek, surface of water	1,565
19.6	Surface of water	1,559
20	Mouth of Charlie Creek, surface of water	1,555
20	Lovingood Ford, 300 feet northeast of, nail in side of walnut tree	1,564.61
20	Surface of water	1,554
20	High-water mark	1,569
21.5	Mouth of Star Creek, surface of water	1,550
21.6	Below fish dam, surface of water	1,548
22	Mouth of Rogers Branch, surface of water	1,547
22.4	Toccoa Bridge, surface of water	1,546
22.4	Toccoa Bridge, 10 feet east of, nail in root of beech tree	1,557.64
22.9	Mouth of spring stream, surface of water	1,540
23.5	Below small rapids, surface of water	1,539
23.6	Mouth of Weavers Creek, surface of water	1,538
23.9	At Benchlog Ford, surface of water	1,538
23.9	Benchlog Ford, 20 feet northeast of, nail in side of beech tree	1,543.47
25.2	Large bend in river, surface of water	1,528
25.5	Atlanta, Knoxville and Northern Railroad bridge, east side of bridge abutment, point on rock	1,536.79
25.5	Surface of water	1,526
25.5	High-water mark	1,541
26.6	Mouth of branch, surface of water	1,519
26.8	Harts Ford, 100 feet west of, stump on edge of bank at canoe landing, nail in side of	1,521.90
26.8	Surface of water	1,516
28	Surface of water	1,510
28.8	Bakers Ford, 100 feet southeast of, on edge of bank, nail in side of birch tree	1,515
28.8	Surface of water	1,507
29.6	Surface of water	1,504
30	Bend of river, surface of water	1,502

Elevations on Toccoa River from Butts Bridge, Georgia, to Tennessee State line—Continued.

Distance in miles.		Elevation in feet.
	Single flying level spur line to McCays Ferry—Continued.	
30.2	Surface of water	1,498
30.9	Mouth of Sugar Creek, surface of water	1,494
30.9	Sugar Creek railroad bridge abutment, point in center of east side of bridge	1,508.32
31.2	Below Galloway Ford, surface of water	1,592
31.5	In shoals, surface of water	1,589
32.1	200 feet northwest of ford, 4 feet southeast of Atlanta, Knoxville and Northern Railroad track, nail in side of peach tree	1,562.69
32.1	Surface of water	1,484
32.5	Canoe Landing, surface of water	1,479
32.8	Hothouse Creek, mouth of, surface of water	1,476
33.7	Foot of small shoals, near island, surface of water	1,467
34	Mouth of Barker Creek, surface of water	1,464
34.5	Kyle post-office, 600 feet east of, Atlanta, Knoxville and Northern Railroad bridge over Barker Creek, on southeast end of, end bolt	1,482.43
34.6	Kyle post-office, 40 feet south of, in front of Queen Brothers' store, pile supporting platform, nail in top of	1,483.62
34.6	Kyle ford, surface of water	1,463
35	Below rapids, surface of water	1,458
35.4	Mouth of Wolf Creek, surface of water	1,455
35.8	Atlanta, Knoxville and Northern Railroad bridge over Ocoee River, east side of bridge, point on abutment	1,471.98
35.8	Surface of water	1,452
36.1	In bend of river, surface of water	1,450
36.3	Dillbeck Ford, north edge of river, nail in side of dead birch tree	1,451.87
36.3	Surface of water	1,447
37.5	McCays post-office, Polk County, Tenn., rock supporting southwest corner of, point on	1,468.07
37.5	McCays Ferry, north side of river, pile supporting swinging bridge, cartridge shell in top of	1,460.15
37.5	High-water mark	1,469
37.5	Surface of water	1,444

CHIPPEWA RIVER FROM REEDS LANDING, MINNESOTA, TO FLAMBEAU, WIS.

Between April 15 and June 12, 1903, J. R. Ellis, field assistant, ran a careful double-rodded primary-level line along the Chippewa River from Reeds Landing, Minnesota, to Chippewa Falls, Wis. This work was under the general direction of J. H. Renshawe, geographer in charge of the central section of topography. Later in the year it was decided to continue this work above Chippewa Falls, and on

September 1 the central and eastern sections having united as the eastern section of topography, H. M. Wilson, geographer in charge, assigned F. T. Fitch, field assistant, to this work. Between that date and October 4 Mr. Fitch ran a line of flying levels accompanied by a plane-table stadia traverse and topographic sketching from Chippewa Falls to Flambeau, Wis.

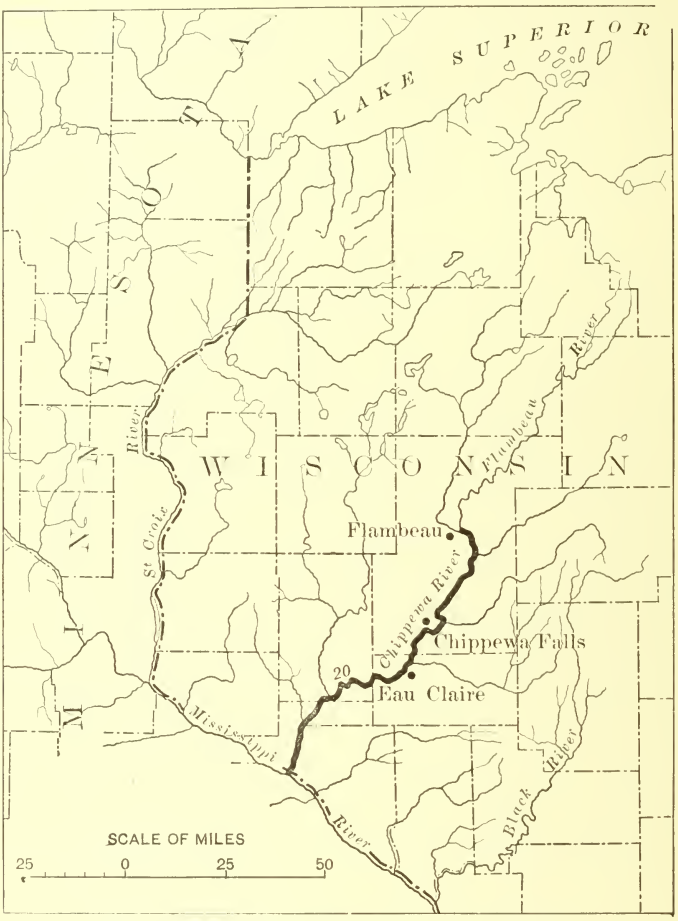


FIG. 17.—Map showing location of surveys in Wisconsin.

This level work is based on a bench mark of the Mississippi River Commission at Reeds Landing, and the distances were obtained by pacing. No plane-table survey of the river was undertaken. In this section, 64 miles in length, there is a fall of 135 feet. Eleven bench-mark tablets and 70 temporary bench marks were established, and 72 water-surface elevations were determined.

While the survey was being made the stage of the river fluctuated greatly, owing to rains and to alternate flooding and stoppage

of the stream by various lumber companies. This diversion of the water is the cause of much complaint by the various mill owners, many of whom want a system of reservoirs constructed near the headwaters to regulate the water supply.

Owing to the slight fall, the width of the stream, and the wide bottom lands, there are no opportunities for power development upon the Chippewa above Reeds Landing until the city of Eau Claire is reached.

On Eau Claire River, a few hundred feet above its junction with the Chippewa at Eau Claire, is a 13-foot dam 300 feet long, which furnishes power for a linen mill. A few miles above the city of Eau Claire on Chippewa River the Dells Paper Company has a 20-foot dam which might be raised 3 or 4 feet by the use of flashboards. There are no power sites on Chippewa River until the city of Chippewa Falls is reached, but there are good prospects of developing power on several of the tributaries between these cities.

From Chippewa Falls to Flambeau the stadia survey of the river and adjacent banks was plotted on a scale of 1:22,500. In this distance, 43 miles, there is a total fall of 244 feet. Seven bench marks were established and 40 water-surface elevations were determined.

At Chippewa Falls a wooden 13-foot dam, owned by the Chippewa Falls Lumber and Boom Company, increases the head to 30 feet and supplies power for a large sawmill, and an electric plant which furnishes the city of Chippewa Falls with water and light. This dam could be made higher, as the local conditions are favorable, but this would interfere with a proposed plant at Paint Creek Rapids, 2½ miles upstream, to which point the water now backs up. Here there was formerly a flooding dam, but a freshet cut a channel around it to the north, and the dam has since been torn out. A 14-foot dam could be constructed at the foot of the rapids where the banks and bed of the river are sand intermingled with large bowlders. Abundant stone for construction is near at hand.

At Eagle Rapids, 4½ miles upstream, is a good site for a dam. A dam here was torn out. A 20-foot dam would back water three-fourths of a mile above the city of Chippewa, where O'Neils Creek enters from the west. One mile above O'Neils Creek is a gorge 700 feet wide. A 25-foot dam would have solid sandstone for foundation and abutments and would back water almost to the foot of Jim Falls, 5 miles above. At the small village of Jim Falls, near the site of an old flooding dam, is the best opportunity for power development on the river. This point is now under development, the company having purchased all the land needed as well as the water rights. The river flows over a series of granite ledges from 1 to 4 feet high, while the banks seem to be solid rock covered by a

few feet of sandy soil. The proposed dam will be 28 feet high and will be located at the head of the rapids. It will furnish power for a pulp mill. The dam will back water nearly to Brunne Falls, 9½ miles, and covers the Colton and Chevalley rapids. The head obtained by this dam will be 55 feet.

At Brunne Falls the best location for a dam would be at the main fall, about 650 feet above the foot of the rapids, where a 35-foot dam would back the water up to the rapids at Holcombe, 5½ miles. The river at the falls is very narrow, and at the point mentioned the banks are ledges of rock. A rocky island in the river would help in the construction a good deal.

At Holcombe the Chippewa Falls Lumber and Boom Company has an old dam with a head of about 17 feet. This is the third dam they have built there, the others having been washed out by freshets. As the lumber interests in this locality are declining, the present dam is being allowed to decay, and could be replaced with a more substantial structure for power purposes. The river here has a rock bottom and rather low, clay sides, and an 18-foot dam could be constructed on the site of the present structure, which, together with a 15-foot dam at the foot of the rapids, would not destroy any more valuable bottom lands above. This would back the water up for more than a mile above Deer Tail Creek and furnish considerable storage. From here to Flambeau, the end of the survey, there are no rapids of any consequence.

There are two railway bridges and a highway bridge across the river at Chippewa Falls and another road bridge just below Eagle Rapids. There are but few boats on the river, as during the log-driving season boats would be crushed.

The lumbering operations, which are on the decline, are controlled by the Chippewa Falls Lumber and Boom Company, with headquarters at Chippewa Falls, a thriving city of about 10,000 population, where there are a number of factories and mills. About ten miles above is the city of Chippewa, at one time the most promising town in the neighborhood, but now little more than a hamlet. At Jim Falls there is a village, but Holcombe is the only town of any importance above Chippewa Falls. Several railroad lines are being built in this section, and the agricultural and manufacturing interests are supplanting the lumber industry, while the land is generally taken up by settlers wherever the lumber has been cut, so that no second-growth timber is coming up. The whole community seems very prosperous, while numerous companies are on the point of investing capital in the manufacturing interests in the neighborhood.

The elevations of water surfaces of the river are dependent on the following table of daily gage readings by the Chippewa Falls

Lumber and Boom Company from a gage on the highway bridge at Chippewa Falls. The elevation of the zero of gage is 804.8 feet above sea level. The gage height of the highest water known had an elevation of 831.4 feet above sea level.

Gage height of Chippewa River at Chippewa Falls.

Date.	Height.		Date.	Height.	
	Ft.	*In.*		*Ft.*	*In.*
May 1	8	10	June 6	3	10
2	8	6	7	2	2
3	8	0	8	2	6
4	8	0	9	3	0
5	7	9	10	2	9
6	7	3	11	2	6
7	6	8	12	2	6
8	5	6	13	2	2
9	5	6	14	.....	
10	.....		15	1	6
11	5	6	16	1	6
12	8	9	17	1	6
13	9	6	18	1	3
14	9	6	19	0	6
15	9	1	20	2	6
16	8	1	21	.....	
17	.....		22	1	0
18	6	3	23	1	3
19	5	8	24	1	0
20	5	2	25	0	9
21	5	3	26	0	9
22	5	8	27	0	9
23	5	3	28	.....	
24	.....		29	1	6
25	5	9	30	1	10
26	6	4	July 1	3	8
27	8	8	2	4	10
28	11	0	3	5	7
29	12	5	4	9	6
30	11	8	5	10	6
31	10	3	6	10	3
June 1	8	8	7	9	0
2	7	10	8	7	9
3	6	6	9	6	9
4	5	9	10	5	1
5	4	9	11	6	0

Gage height of Chippewa River at Chippewa Falls—Continued.

Date.	Height.		Date.	Height.	
	Ft.	*In.*		*Ft.*	*In.*
July 12	6	0	Aug. 22	1	[illegible]
13	5	4	23	.....	
14	4	6	24	1	[illegible]
15	4	3	25	1	[illegible]
16	3	3	26	1	[illegible]
17	3	3	27	1	[illegible]
18	5	0	28	2	[illegible]
19	1	0	29	2	[illegible]
20	2	10	30	2	[illegible]
21	2	6	31	2	[illegible]
22	2	3	Sept. 1	2	[illegible]
23	2	3	2	2	[illegible]
24	2	3	3	2	[illegible]
25	3	0	4	2	[illegible]
26	.....		5	.....	
27	2	6	6	2	[illegible]
28	1	9	7	2	[illegible]
29	1	6	8	2	[illegible]
30	1	4	9	4	[illegible]
31	1	0	10	4	[illegible]
Aug. 1	1	3	11	5	[illegible]
2	1	6	12	7	[illegible]
3	2	0	13	7	[illegible]
4	2	9	14	9	[illegible]
5	3	6	15	12	[illegible]
6	5	3	16	13	[illegible]
7	5	3	17	12	[illegible]
8	6	9	18	11	[illegible]
9	3	6	19	9	[illegible]
10	3	10	20	8	[illegible]
11	3	8	21	7	[illegible]
12	3	0	22	6	[illegible]
13	3	3	23	5	[illegible]
14	3	2	24	4	[illegible]
15	3	6	25	3	3
16	.....		26	3	3
17	3	0	27	3	3
18	2	6	28	3	4
19	2	0	29	3	3
20	1	6	30	3	3
21	1	6	Oct. 1	3	3

Gage height of Chippewa River at Chippewa Falls—Continued.

Date.	Height.		Date.	Height.	
	Ft.	*In.*		*Ft.*	*In.*
ct. 2	3	3	Oct. 5	7	10
3	3	6	6	8	1
4	5	9	7	8	0

The elevations in the following list are based upon a bronze tablet, ıarked "797 E. C," at southwest corner of the court-house at Eau laire, Wis., the elevation of which is accepted as 797.473 feet above ıean sea level. The initial point upon which these levels depend is ench mark "Bottom," of the Missouri River Commission, opposite ieeds Landing, Minnesota, the elevation of which is accepted as 72.355 feet above mean sea level. These elevations accord with he 1903 adjustment of the precise-level net.

Permanent bench marks dependent on this datum are marked with he letters " E. C." in addition to the figures of elevation.

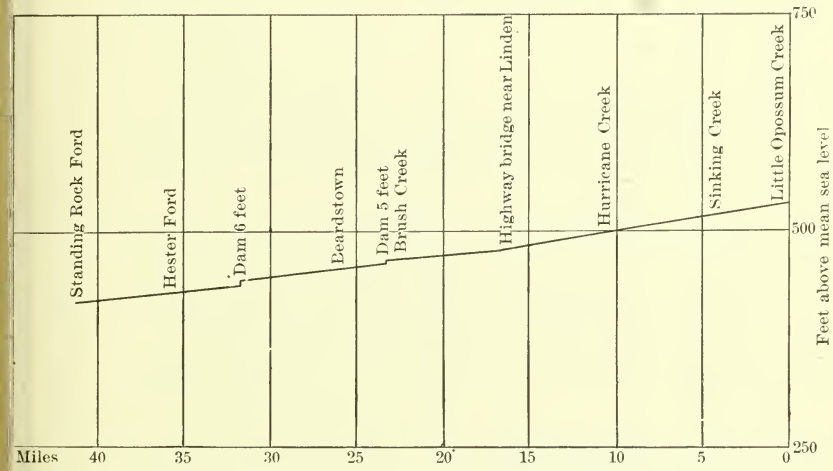


FIG. 18. Profile of Chippewa River from Reeds Landing, Minnesota, to Flambeau, Wis.

levations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.

Distance in miles.		Elevation in feet.
0.0	Reeds Landing, Minnesota (Miss. River Commission bench mark "Bottom"), tile and iron pipe in low flat ground, opposite, 220 meters from left bank of river, in property of Mrs. C. S. Richards, 45 meters west of Chicago, Milwaukee and St. Paul Railroad trestle to bridge, 205 meters southwest of end of trestle and small pond.	672.355

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
0.5	High water in back water of slough	672
1.4	Trevin's, at grade crossing Burlington and Chicago, Milwaukee and St. Paul railroads, top of rail	684.3
1.4	15 feet northwest of intersection of grade crossing, spike in telegraph pole	684.89
1.9	15 feet northwest of end of trestle, nail in top of fence post	680.01
2.6	Lone narrow island, lower end of, left bank of river, birch tree, nail in root of	677.46
2.6	High water	674
3.2	Private road crossing, top of rail	681.4
3.5	Government dam, 300 feet below, opposite north end of small island, left bank of river, water maple, nail on notch	680.36
3.5	High water	675
3.6	300 feet north of rapids, high water	676
3.8	Wancuda Island, 0.25 mile below north end of, left bank of river, notch cut on elm tree, nail in	681.52
4.3	North end of Government dam, 100 feet below, left channel, surface of water	677
4.5	165 feet east of river, water maple tree, notch cut in	681.13
4.5	Surface of water	678
0	Near north corner of C. W. Knight's yard, in top of limestone 8 by 10 by 26 inches, set 25 inches in ground, bronze tablet marked "682 E. C."	682.337
5.5	Opposite trestle 32 H, surface of water	680
5.8	Old Battle Slough station, in west side of switch stand, spike	685.28
6.2	Surface of water (river about 1 foot above ordinary stage)	681
6.6	Bridge No. 38 M, 50 feet south of, west side of dump, cross on stone	685.28
6.7	Bridge No. 42 M, private road crossing south of, top of rail	688.41
7.4	Bridge No. 50 M, at south end of, east side of track, nail in cross cut in cap	688.26
7.4	Surface of water	683
7.9	Private crossing, top of rail	692.1
7.9	Surface of water	685
8	Second telegraph pole north of slough, spike in	689.33
8.5	Elm tree on left bank of river, nail in notch cut in	689.36
8.5	Surface of water (1.9 feet higher than stage observed nearer mouth)	687
9	Trestle No. 60 M, top of rail	.....
9	Surface of water	688
9.6	Maxwell station, surface of water	691
9.6	Maxwell, 180 feet southwest of platform, in sandstone post 8 by 12 by 80 inches, set 27 inches in ground, bronze tablet marked "691 E. C."	691.196
10.3	Trestle No. 66 M, Little Belf Slough, surface of water	691

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
10.6	West side of railroad, near gate at private road crossing, nail in top of stump	694.91
10.6	Surface of water (is about 4 feet lower than low water)	693
11.4	South end of trestle No. 70 M, 15 feet east of railroad, cross on sandstone	701.32
11.9	Big Beef Slough, 150 feet below railroad bridge No. 74 M (is about 3 feet above low water) surface of water	695
12.3	595 feet north of bridge, on west side of track, nail in top of post	711.65
12.4	Private road crossing, top of east rail	714.61
12.8	Pawn's farm, private road crossing, top of west rail	724.3
13.4	T. 24 N., R. 13 W., just outside of Chicago, Milwaukee and St. Paul Railroad right of way, left bank of river, and 0.25 mile due west of center sec. 6, in sandstone post 12 by 6 by 30 inches, bronze tablet marked "733 E. C."	732.878
13.4	Surface of water	698
14	Round Hill, 0.25 mile below, left bank of river, black oak tree, nail in notch cut in	737.7
14	Surface of water	699
14.4	Road in front of barn	733
14.4	Surface of water	699
14.6	Round Hill, north and south road crossing on Chicago, Milwaukee and St. Paul Railroad	731.4
15.2	Road crossing on east side of railroad, spike in signboard	740.56
15.9	Private road crossing, top of rail	724.55
16.1	Durand, 100 feet north of south switch block, 12 feet east of center of track, north end of sandstone, cross	717.54
16.5	300 feet north of brewery, east and west road crossing, top of rail	720.6
16.8	Durand, road crossing north of station, top of rail	724.7
16.8	Durand County jail building, water table at southwest corner of, bronze tablet marked "724 E. C."	724.361
16.8	Upper bridge, surface of water	703
17.5	Durand, north part of, at north end of siding, 35 feet northwest of switch block, cottonwood tree, notch cut in root, nail in	727.23
	Spur line up river.	
18.2	Elm tree, left bank of river, nail in notch	707.24
18.2	Surface of water	705
18.5	Creek from east, white oak tree at, nail in notch on root	707.20
18.5	Creek, at mouth, surface of water (river is about 2 feet above low water)	706
	Main line continued.	
18.8	Northwest corner of trestle No. 96 M, nail in top of fence post	717.24
18.8	Surface of water	711
19.1	Beaver Creek, surface of water	712

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
19.1	Trestle No. 98 M, top of sandstone, at southeast end of trestle	714.55
19.7	Trestle No. 100 M, southeast corner of, spike in cap	715.60
19.7	Surface of water	713
20.4	Bear Lake, 0.75 mile north of, private road crossing, top of west rail	733.2
20.6	Private road crossing, top of east rail	735.1
21.1	Whistle post for road crossing, spike in	735.62
21.2	East and west road crossing, top of west rail	735.8
21.4	Northwest and southeast road crossing, top of west rail	737.2
22.1	Weber's house, road crossing, top of rail	745.8
22.1	Crossing post, near bottom, railroad spike	746.52
22.4	Trestle No. 106 M, section line between secs. ——— top of rail	749.64
22.8	Red Cedar, 0.33 mile south of, T. 25 N., R. 12 W., sec. 6, one-quarter corner north side of, in ground at T road east, sandstone 6 by 12 by 30 inches, bronze tablet marked "755 E. C."	755.670
23.1	Red Cedar, west part of, foundation to water tank	758.36
23.1	Red Cedar, road crossing, top of rail	758.9
23.3	Surface of water	721
23.9	Private road crossing, top of rail	735.2
24	Private road crossing, spike in base of first telegraph pole north of	731.37
24.2	Red Cedar Junction, at switch block, top of east rail	729.3
24.4	Red Cedar Junction, surface of water at bridge	721
24.6	Trestle No. 108 M, at southwest corner, nail in top of fence post	730.45
24.6	Surface of water	722
25.7	Tyrone (abandoned station), 750 feet south of, spike in telegraph pole	727.97
25.7	Surface of water	724
25.8	Tyrone, at road crossing, top of rail	732
26.4	Private road crossing, top of rail	731.2
26.7	Trestle No. 116, fence post at southwest corner of, nail in top of	732.96
26.7	Surface of water	724
26.9	Private road crossing, top of west rail	733.24
27.1	Railroad spike in crossing post	731.5
27.4	Road crossing (second one north of public crossing), top of rail	732.9
27.9	Trestle No. 118 M, at southeast corner of, in top of fence post	733.04
27.9	Surface of water	728
28.8	Meridian, T. 26 N., R. 12 W., sec. 14, north part of, at southeast corner of Iver Brock's residence, in stone foundation, bronze tablet marked "740 E. C."	739.923
28.8	Road crossing, top of rail	739.2
29.4	Private road crossing, top of rail	739.8
29.6	Trestle No. 124 M, at east end of, nail in top of fence post	738.46

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
29.6	Surface of water	733
29.7	North and south road crossing, top of rail	739.6
30.1	North and south road crossing, cross on stone	740.30
30.1	Road crossing, top of north rail	741.7
31	Road crossing, spike in telegraph pole	745.02
31	Wagon bridge, surface of water	739
32.2	South side of railroad, 60 feet west of large spring, cross cut in sandstone	751.82
32.2	Surface of water	741
33	Spike in base of telegraph pole	747.85
33.7	Opposite small island, on highest point of large sandstone bowlder, cross cut	753.19
33.7	Surface of water	743
34.1	On bank of river at right of way fence, sandstone bowlder, cross cut in top of	754.70
34.5	Rock Creek, surface of water	744
34.7	Private road crossing, top of rail	752.9
34.9	Trestle No. 144, at northwest corner of, nail in cross cut in cap	751.22
35.8	Caryville, T. 26 N., R. 11 W., sec. 11, east part of, at northwest corner of post-office, Strand's general store, in stone foundation, bronze tablet marked "760 E. C."	760.144
35.9	Road crossing, top of rail	757.7
	[Line continued along highway.]	
36.3	Wagon bridge over West Creek, in top of pile at east approach, nail	753.98
36.3	Surface of water	746
37	East of small island, water maple 40 feet east of river, on left bank, nail in root of	749.63
37	Surface of water	747
38.3	Powell Lake and Chippewa River roads, 75 feet east of junction, small double elm tree, nail in root of	756.15
39.1	Surface of water	752
39.5	Surface of water	752
40.7	On left bank of river, at east end of long log boom, nail in maple stump	763.11
40.7	Surface of water	755
41.3	Coolies Lake, near outlet, B. A. Churchville residence, at southwest corner of, in foundation, bronze tablet marked "779 E. C."	779.356
41.4	Surface of water	758
42.4	Porterville, 0.75 mile south of, wagon road culvert, nail in top of pile	763.92
42.4	Surface of water	761
43	Old Porter mills, nail in root of large water maple	764.84
43.3	T roads	767

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
43.3	Creek, mouth of, surface of water	764
43.8	On river bank, 30 feet west of road, nail in top of stump	767.85
44.1	Surface of water	764
44.8	Charles Bannon's residence, 120 feet southeast of, at gate, nail in white oak stump	771.08
44.9	Lower Creek, road crossing on Chicago, Milwaukee and St. Paul Railroad, top of rail	773.4
44.9	Surface of water (higher than has been for 2 years)	768
45.5	Shawtown, 1 mile south of, T. 27 N., R. 10 W., sec. 36, northeast corner of, in stone foundation at northwest corner of Henry Trimble's residence, bronze tablet marked "781 E. C."	780.84
45.5	High water, in 1884	777
45.8	Road crossing	776.5
45.8	Surface of water	769
46.5	Shawtown, 200 feet south of railroad bridge, spike in base of telegraph pole	783.98
46.5	Under bridge, surface of water	769
46.6	Menomonie street crossing, top of rail	777.6
47.6	Eau Claire, crossing of Niagara and Seventh street	781.2
48.1	East entrance to high school, first window to right, in sill, cut in center	797.93
48.3	Eau Claire, at southwest corner of court-house, bronze tablet marked "797 E. C."	797.473
48.4	Crossing of Grand and Oxford avenue, top of rail	791
48.7	200 feet south of railroad bridge, spike in base of crossing post	787.33
48.8	Center of railroad bridge over river	788.3
48.8	Eau Claire River, mouth of, surface of water under bridge (June 2)	770
	[Spur line, June 9, up Eau Claire River from junction. Stage of water 6.5 lower.]	
.1	Junction of Chippewa and Eau Claire rivers, June 9, foot of first dam at mouth of, on Eau Claire river	763.5
.1	Head of same dam	774
75	Foot of second dam	774
.75	Head of second dam	786.8
	[Main line continued June 2. River is 6.5 feet higher than a week later.]	
49	Eau Claire court-house, 0.7 mile north of, at Chicago, Milwaukee and St. Paul Railroad station, top of rail	786.05
49.1	Forrest street crossing of spur to paper mill, top of rail	778.6
49.4	Elm street crossing, top of rail	780.3
49.4	The Dallas Paper Mill Company dam, foot of, surface of water	772
49.4	The Dallas Paper Mill Company dam, head of, surface of water	793
49.8	Chicago and Northwestern Railroad bridge over river, south corner of east pier, cross cut on	804.36

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
50.6	Chicago and Northwestern, at mile post St. Paul 87, top of rail	843.1
50.7	Duluth Branch, at overhead road crossing, top of rail	851.8
50.8	Duluth branch, Chicago and Northwestern Railroad, on east side of railroad, opposite yard-limit post, spike in base of telegraph pole	858.56
51	Road crossing, top of rail	871.3
51.4	Mile post 1, top of east rail	882.8
51.6	Power house at crossing of Chicago, Milwaukee and St. Paul and Chicago and Northwestern railroads, 1,100 feet south of, spike in telegraph pole	882.09
51.9	Grade crossing, top of rail	881.2
52	Chicago, Milwaukee and St. Paul and Chicago and Northwestern railroads, grade crossing, top of rail	880.2
52.6	Road crossing, top of west rail	843.5
52.6	20 feet west of north cattle guard to road crossing, in base of fence corner post, spike	840.09
53.2	Road crossing, top of rail	813.8
53.3	Second pole west of road crossing, spike in	807.97
53.5	Dalles Mill station, road crossing, top of west rail	804.2
54.4	Road crossing on line between Eau Claire and Chippewa counties	813
54.4	County line crossing, in north cattle guard, nail in top of fence post	815.18
54.8	East and west road crossing, top of east rail	821.1
54.8	Surface of water	793
56.1	La Fayette, road crossing at old site of, top of west rail	817.4
56.1	Surface of water	794
56.1	La Fayette, second telegraph pole above road crossing at old site of, spike in	818.75
57.3	North and south private road crossing, spike in black oak tree	815.96
.0	Surface of water	794
57.4	Road crossing east and west	821.9
58.3	Badger Mills, road crossing just below north switch block	817
58.3	Halle Lake, Badger Mills, surface of water	815
58.4	Badger Mills, just south of waiting shed, spike in crossing post	818.19
58.4	Badger Mills, opposite waiting shed, top of east rail	820.2
58.76	Badger Mills, summer hotel, in ground in lawn of, 50 feet due west of front window, sandstone post 10 by 8 by 30 inches, bronze tablet marked "827 E. C."	827.716
59.4	150 feet west of P. C. mark, 150 feet south of gate, spike in base of telegraph pole	831.45
59.4	Surface of water	797.3
60.5	Surface of water	801
60.6	Trestle No. 216, in sleeper at west end of, painted cross on bolt	833.51
61.1	Gravel Island, crossing post just below, spike in base of	855.19
61.1	Gravel Island, slough, mouth of, surface of water	803

Elevations on Chippewa River from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
62.1	Surface of water	805
62.2	Spike in base of crossing post	840.31
62.2	Road crossing, top of rail	842.4
62.8	Central Junction, Chicago, Milwaukee and St. Paul Railroad and Wisconsin Central Railroad, switch block at	832.4
62.9	East side of railroad, spike in base of telegraph pole	832.9
62.9	Road crossing, top of rail	833.9
63	Center of Chicago, Milwaukee and St. Paul Railroad bridge, top of rail	834.03
63	Surface of water under bridge	805
63.3	Junction of Chicago, Milwaukee and St. Paul Railroad and Wisconsin Central Railroad (main line), top of rail	840.3
63.8	Chippewa Falls, 20 feet south of water tank, spike in base of telegraph pole	830.63
63.9	Chippewa Falls, Taylor street crossing, top of rail	833.7
63.9	Chippewa Falls, under bridge, foot of dam, surface of water	807
64.31	Chippewa Falls, northeast corner of city building containing fire department and city jail, in foundation, bronze tablet marked "840 E. C."	840.468
64.4	Chippewa Falls, above dam, surface of water	840
	[Flying levels by F. T. Fitch, field assistant, Chippewa Falls, up Chippewa River to Flambeau.]	
.0	Highest water mark on record, recorded by Chippewa Falls Lumber and Boom Company, Sept. 10, 1884	832
.0	Second highest water mark of Chippewa River, recorded Dec. 3, 1896	831
.0	Lowest water mark of Chippewa River, reading taken at Chippewa Falls	804
.0	Highway bridge at falls, surface of water	806
.0	Chippewa Falls, surface of water	826
.0	Crest of dam of Chippewa Falls Lumber Company, surface of water	839
3.7	Paint Creek Rapids, foot of, north bank of river, 50 feet from water, top of bowlder, chiseled square	844.54
5.5	Yellow River, mouth of, surface of water	852
8	Eagle Rapids, foot of, surface of water	854
9.2	Eagle Rapids, head of, surface of water	867
10.7	Surface of water	871
13	Foot of rapids, surface of water	881
15.7	Jim Falls, east side of river at edge of water, nearly opposite Pitch Hotel, at foot of rapids, in granite ledge, chiseled square	902
15.7	Surface of water	901
16.6	Head of rapids, surface of water	936
17.9	Coltons Rapids, foot of, surface of water	942.2
19.2	Coltons Rapids, head of, surface of water	945

Elevations on Chippewa River, from Reeds Landing, Minnesota, along Chicago, Milwaukee and St. Paul Railroad, to Chippewa Falls, Wis.—Continued.

Distance in miles.		Elevation in feet.
19.2	Chas. Richards, near house occupied by, 150 feet south of road intersection, at edge of water, rock, chiseled square	947.40
20.2	Shaw Creek, 400 feet above mouth of, surface of water	.....
22.9	Bob Creek, mouth of, surface of water	954
25.7	Chevalley Rapids, foot of, surface of water	961
26.9	Above rapids, surface of water	966
26.9	Brunne Falls, at boat landing, west bank of river, below main falls and just above Chevalley Rapids, 125 feet south of old house, 50 feet from water, bowlder 2 feet square, chiseled square	984.19
27	Brunne Rapids, foot of, surface of water	967
28	Brunne Rapids, head of, surface of water	993
29.5	Fisher River, mouth of, surface of water	995
32.7	Holcombe, foot of rapids, surface of water	1,004
33.2	Holcombe, foot of dam, surface of water	1,020
33.2	Above dam, surface of water	1,036
33.2	South entrance to bridge over flooding dam, 500 feet west of, south side of highway, 50 feet south of river, on bowlder in fence, chiseled square	1,046.55
39.7	Deer Tail Creek, mouth of, surface of water	1,036
43.3	Flambeau, post-office, at intersection of Flambeau and Chippewa rivers, on point of land, nail in root of tree	1,055.09
43.3	Junction of rivers, surface of water	1,050

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Progress reports may be found in the following publications: For 1888–89, Tenth Annual, Pt. II; for 1889–90, Eleventh Annual, Pt. II; for 1890–91, Twelfth Annual, Pt. II; for 1891–92, Thirteenth Annual, Pt. III; for 1893–94, B. 131; for 1895, B. 140; for 1896, Eighteenth Annual, Pt. IV, WS 11; for 1897, Nineteenth Annual, Pt. IV, WS 15, 16; for 1898, Twentieth Annual, Pt. IV, WS 27, 28; for 1899, Twenty-first Annual, Pt. IV, WS 35–39; for 1900, Twenty-second Annual, Pt. IV, WS 47–52; for 1901, WS 65, 66, 75; for 1902, WS 82–85; for 1903, WS 97–100.

Correspondence should be addressed to

The Director,
United States Geological Survey,
Washington, D. C.

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Water-Supply and Irrigation Paper No. 116

Series { J, Water Storage, 11
M, General Hydrographic Investigations, 14

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

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WATER PROBLEMS

OF

SANTA BARBARA, CALIFORNIA

BY

J. B. LIPPINCOTT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

The publications of the United States Geological Survey consist of (1) Annual Reports; (2) Monographs; (3) Professional Papers; (4) Bulletins; (5) Mineral Resources; (6) Water-Supply and Irrigation Papers; (7) Topographic Atlas of United States, folios and separate sheets thereof; (8) Geologic Atlas of United States, folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

The Professional Papers, Bulletins, and Water-Supply Papers treat of a variety of subjects, and the total number issued is large. They have therefore been classified into the following series: A, Economic geology; B, Descriptive geology; C, Systematic geology and paleontology; D, Petrography and mineralogy; E, Chemistry and physics; F, Geography; G, Miscellaneous; H, Forestry; I, Irrigation; J, Water storage; K, Pumping water; L, Quality of water; M, General hydrographic investigations; N, Water power; O, Underground waters; P, Hydrographic progress reports.

The following Water-Supply Papers are out of stcok, and can no longer be supplied: Nos. 1-16, 19, 20, 22, 29-34, 36, 39, 40, 43, 46, 57-65, 75. Complete lists of papers relating to water supply and allied subjects follow. (PP=Professional Paper; B=Bulletin; WS=Water-Supply Paper.)

Series I—Irrigation.

WS 2. Irrigation near Phoenix, Ariz., by A. P. Davis. 1897. 98 pp., 31 pls. and maps.
WS 5. Irrigation practice on the Great Plains, by E. B. Cowgill. 1897. 39 pp., 11 pls.
WS 9. Irrigation near Greeley, Colo., by David Boyd. 1897. 90 pp., 21 pls.
WS 10. Irrigation in Mesilla Valley, New Mexico, by F. C. Barker. 1898. 51 pp., 11 pls.
WS 13. Irrigation systems in Texas, by W. F. Hutson. 1898. 68 pp., 10 pls.
WS 17. Irrigation near Bakersfield, Cal., by C. E. Grunsky. 1898. 96 pp., 16 pls.
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WS 23. Water-right problems of Bighorn Mountains, by Elwood Mead. 1899. 62 pp., 7 pls.
WS 32. Water resources of Porto Rico, by H. M. Wilson. 1899. 48 pp., 17 pls. and maps.
WS 43. Conveyance of water in irrigation canals, flumes, and pipes, by Samuel Fortier. 1901, 86 pp., 15 pls.
WS 70. Geology and water resources of the Patrick and Goshen Hole quadrangles, Wyoming. by G. I. Adams. 1902. 50 pp., 11 pls.
WS 71. Irrigation systems of Texas, by T. U. Taylor. 1902. 137 pp., 9 pls.
WS 74. Water resources of the State of Colorado, by A. L. Fellows. 1902. 151 pp., 14 pls.
WS 87. Irrigation in India (second edition), by H. M. Wilson. 1903. 238 pp., 27 pls.
WS 93. Proceedings of first conference of engineers of the reclamation service, with accompanying papers, compiled by F. H. Newell, chief engineer. 1904. 361 pp.

The following papers also relate especially to irrigation: Irrigation in India, by H. M. Wilson, in Twelfth Annual, Pt. II; two papers on irrigation engineering, by H. M. Wilson, in Thirteenth Annual, Pt. III.

Series J—Water Storage.

WS 33. Storage of water on Gila River, Arizona, by J. B. Lippincott. 1900. 98 pp., 33 pls.
WS 40. The Austin dam, by Thomas U. Taylor. 1900. 51 pp., 16 pls.
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WS 46. Physical characteristics of Kern River, California, by F. H. Olmsted, and Reconnaissance of Yuba River, California, by Marsden Manson. 1901. 57 pp., 8 pls.
WS 58. Storage of water on Kings River, California, by J. B. Lippincott. 1902. 100 pp., 32 pls.
WS 68. Water storage in Truckee Basin, California-Nevada, by L. H. Taylor. 1902. 90 pp., 8 pls.
WS 73. Water storage on Salt River, Arizona, by A. P. Davis. 1902. 54 pp., 25 pls.
WS 86. Storage reservoirs on Stony Creek, California, by Burt Cole. 1903. 62 pp., 16 pls.
WS 89. Water resources of Salinas Valley, California, by Homer Hamlin. 1904. 91 pp., 12 pls.
WS 93. Proceedings of first conference of engineers of the reclamation service, with accompanying papers, compiled by F. H. Newell, chief engineer. 1904. 361 pp.
WS. 116. Water problems of Santa Barbara, Cal., by J. B. Lippincott. 1905. 99 pp., 8 pls.

The following paper also should be noted under this heading: Reservoirs for irrigation, by J. D. Schuyler, in Eighteenth Annual, Pt. IV.

[Continued on third page of cover.]

Water-Supply and Irrigation Paper No. 116 Series { J, Water Storage, 11
M, General Hydrographic Investigations, 14

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

WATER PROBLEMS

OF

SANTA BARBARA, CALIFORNIA

BY

J. B. LIPPINCOTT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

Department of the Interior,
United States Geological Survey,
Hydrographic Branch,
Washington, D. C., May 12, 1904.

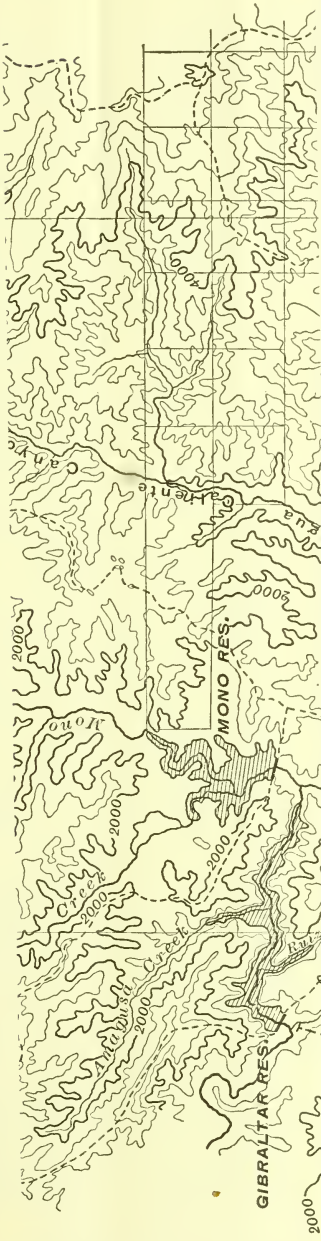
Sir: I have the honor to submit herewith, for publication as a water-supply and irrigation paper, a report on the water problems of Santa Barbara, Cal., transmitted by Mr. J. B. Lippincott.

As the city and suburbs of Santa Barbara form one of the most attractive and productive districts in southern California, a thorough knowledge of the water supply of the region is of the utmost importance. It is thought that the facts brought out in the report will be of much interest.

Very respectfully,

F. H. Newell,
Chief Engineer.

Hon. Charles D. Walcott,
Director United States Geological Survey.



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UPPER DRAINAGE BASIN OF SANTA YNEZ RIVER, ALSO SANTA BARBARA AND VICINITY.

WATER PROBLEMS OF SANTA BARBARA, CAL.

By J. B. Lippincott.

INTRODUCTION.

The Santa Barbara coast extending from Goleta to Carpinteria, including the city and suburbs of Santa Barbara, is naturally one of the most attractive and productive districts of southern California. It is, however, deficient in water supply.

Desiring a broad and comprehensive study made of this locality, with a view to a solution of the problems involved, the city and county of Santa Barbara have requested (1) that the topographic work of the Geological Survey be extended so as to cover this district, and (2) that the hydrographic branch of the Survey make an investigation of the water problems involved. These topographic surveys have now been made, and the maps of the Goleta, Santa Barbara, Santa Ynez, and Mount Pinos quadrangles have been published. The Santa Maria quadrangle has been surveyed and the map is now being engraved. This will complete the mapping of the county. These topographic maps are of the very greatest assistance and importance in determining relative elevations, areas and elevations of drainage basins, and possible tunnel locations through the Santa Ynez Range.

In the hydrographic investigations the city of Santa Barbara has cooperated, paying one-half of the expense connected with the maintenance of a gaging station on Santa Ynez River and Mono Creek, on which streams daily observations have been made for silt, volume of flow, and mineral impurities of the water, and also approximately 25 per cent of the expense connected with the preparation of this report. This portion of the work, therefore, is in the nature of a joint investigation by the city of Santa Barbara and the Geological Survey, all of the field work and investigation being done by the Survey and a portion of the expense being paid by the city of Santa Barbara.

LOCATION AND DRAINAGE OF THE DISTRICT.

The district under investigation extends from Ventura River in Ventura County along the coast as far as Goleta in Santa Barbara County, and more particularly into the high mountainous districts of Ventura and Santa Barbara counties lying on the north side of the Santa Ynez Range and including the drainage basin of Santa Ynez River and its tributaries.

The coastal plain fronting the ocean consists of a series of old marine beaches and undulating foothills facing Santa Barbara Channel. Views of this coastal plain are shown in Pl. II. This district is of great natural beauty, and has become the home not only of agriculturists and horticulturists, but also of many eastern people who have sought it for recreation and health. It is one of the most attractive regions in California. The winds are mild, those from the south being tempered by the Pacific Ocean, and those from the north being barred out by the Santa Ynez Range, which parallels the coast, rising to elevations of from 3,000 to 4,000 feet and presenting a bold and attractive background to the undulating foothill districts. (See Pl. I.)

The streams flowing from the southern slope of this range are precipitous and have short drainage basins of small area. This topography produces a torrential stream condition after rains, followed by a period of extreme low water in time of drought. The range is formed chiefly of shale and sandstone, the strike being parallel to the coast and the dip nearly vertical, inclining somewhat to the south. This geologic formation admits of a number of small but permanent springs in the canyons eroded by the streams, and is also favorable to the development of water by tunnels run at right angles to the line of strike. Beyond the crests of the Santa Ynez Range is the drainage basin of Santa Ynez River. A second range of mountains, consisting of the crest of the Coast Range and culminating in Mount Pinos, the elevation of which is 8,826 feet, rises to the north and trends parallel to the Santa Ynez Mountains. These higher mountains are drained by streams running in a southerly direction and uniting with Santa Ynez River proper, which runs close to the northerly base of the Santa Ynez Mountains, flowing westerly and paralleling the Coast Range. It has a total length of about 70 miles, with flat grades, and offers frequent opportunities for impounding water in storage reservoirs.

The results of the investigations indicate that a solution of the water problem for the coast district lies in impounding the flood waters in the drainage basin of Santa Ynez River and conveying them to Santa Barbara through a long tunnel beneath the Santa Ynez Range.

A

B

VIEWS OF SANTA BARBARA AND VICINITY

REVIEW OF EARLIER WORK BY OTHERS.

It is here deemed proper to review the work which has been done along this line in the past by other engineers, both for the city of Santa Barbara and for the Santa Barbara Water Company. The first report was made for the city of Santa Barbara on October 19, 1889, by George F. Wright, member American Society of Civil Engineers, and at the time city engineer of Santa Barbara. The second report was presented on July 2, 1896, by Ernest J. S. Purslow, civil engineer for the Santa Barbara Water Company. Both of these gentlemen, who are now deceased, were residents of Santa Barbara, engineers of distinction, men of good standing in the community, and thoroughly acquainted with local conditions. In general their judgment respecting the subject here under consideration is approved by the present writer, both from personal knowledge of the locality and from observations elsewhere. Their opinions particularly with reference to local water supplies on the south side of the range are worthy of acceptance, and it was not deemed necessary or advisable to make further field examinations over this ground which they had previously covered in detail. Because these reports were made a long time ago and are now unfamiliar to many new residents, and are out of print, it is considered advisable to briefly review them.

REPORT OF GEORGE F. WRIGHT, 1889.

NEEDS OF DISTRICT.

Mr. Wright states: "I have endeavored to cover the whole field in my report, trusting in many cases to previous examinations and surveys made by myself, aided by the available maps of that portion of the territory lying south of the summit of the Coast or Santa Ynez Range of mountains." He calls attention to the fact that even at that time the city had never had an ample water supply to meet its demands, a condition which, as all the residents of the district are well aware, has never been materially changed. He states further: "The immediate necessity demands a supply of 2 million gallons per day (equivalent to 200 gallons per capita for 10,000 persons), which will certainly be increased to 3 million gallons, and probably 4 million gallons, per day before many years." This statement was made on the assumption that the city, with an ample water supply, would have a vigorous growth, and a development proportional to that of other towns of southern California as suitably located and having adequate supplies. In marked contrast with this demand, he states that the low-water flow of Mission Creek (a present source of supply) is reported to fall as low as 300,000 gallons daily in midsummer, and that a trial test of the De la Guerra wells showed an average daily output of 600,000 gallons at that time.

STREAMS SOUTH OF COAST RANGE.

A complete investigation was made by Wright of all the adjoining drainage basins, extending from Rincon Canyon on the east to Cañada Refugio on the west, during the summer of 1889. The rainfall at Santa Barbara had been 21.44 inches during the preceding winter, and 21.71 inches the winter before that—unusually good records, as the Santa Barbara mean is only 16.78 inches. Consequently Mr. Wright's figures on stream flow are above what should be accepted as an average condition. His table descriptive of the streams is given below.[a]

TABLE 1.—*Streams east of Santa Barbara and south of Coast Range.*

Name of stream.	Catchment area in square miles.	Distance from city in miles.	Daily flow in miner's inches (1889).[b]	Remarks: Flow in miner's inches.
Rincon, proper	8.8	17	5.8	June 16, 1900: 1.5.
Gobernador	7.8	16	29.0	
Carpinteria, including Sutton	5.3	15	3.9	June 16, 1900: 0.1.
Santa Monica	3.6	11	11.6	
Parida, including Oil	3.3	10	15.5	
Ficay	1.4	8	15.5	
Dinsmore	3.0	6	11.6	July 18, 1902: 3.0.
Cold Spring	3.8	4	11.6	
Mission, including Rattlesnake	5.7	1	23.2	June 14, 1900: 1.0. June 17, 1900: 2.5.
Total daily summer flow			127.7	

[a] During the last year the United States Geological Survey has made a detailed topographic field survey of the mountainous district in the vicinity of Santa Barbara, indicating in contours the area of drainage basins, together with their altitude. These maps are more accurate than any previous ones, and have been used in determining the drainage areas of all the streams described by Wright that could be recognized from his names. In each case the area has been determined above the point where the stream issues from the foothills or mountains. In the case of a few of these streams other measurements are available for later years. These are included and show, particularly for the year 1900, a marked decrease in volume over that measured by Wright. The rainfall in the year 1899-1900 at Santa Barbara was 12.68 inches.

[b] A miner's inch is taken as equal to one-fiftieth of a cubic foot per second, or a flow of 12,925 gallons per day.

TABLE 2.—*Streams west of Santa Barbara and south of Coast Range.*

Stream.	Catchment in square miles.	Length in catchment.	Distance from city in miles.	Daily flow in miner's inches.	Remarks: Flow in miner's inches.
Arroyo Burro	.....	2.5	2.5	11.6	June 17, 1900: 1.5.
Maria Ygnacia	5.7	2.0	6.0	[a] 11.6	
San Jose	6.0	2.5	7.0	13.6	July 30, 1900: 38.1.
San Pedro	2.7	2.0	9.5	3.9	
Arroyo Carnero	3.3	2.0	10.0	3.9	
Annes	4.0	1.0	12.0	3.9	
Annito		1.5	13.0	1.9	
Tecolote	5.2	2.5	14.0	13.6	
Aguila	4.5	2.0	15.0	5.8	
Dos Pueblos	6.7	2.0	17.0	27.2	
Cañada Verde (Las Varas)	2.5	2.0	18.0	3.9	
Cañada Llaces	1.5	2.0	20.0	3.9	
El Capitan	1.5	1.0	22.0	11.6	
Cañada del Corral	1.0	1.0	23.0	7.7	
Cañada Refugio	2.0	2.0	25.0	15.4	
Total	.....	.....	.....	139.5	

[a] Laguna Blanca Water Company.

Wright correctly states that the grades of these local streams on the south side of the mountains are very steep, affording no opportunities for the construction of storage reservoirs. He also states that while it might be possible to divert some of these storm waters by means of large canals into basins in the flat lands to the side, the work would be exceedingly expensive and impracticable.

The conclusion that he reaches with reference to the streams on the south side of the Coast Range is as follows:

I do not deem it practicable to secure an ample supply of water for Santa Barbara south of the Santa Ynez Range of mountains, for the following reasons:

1. The aggregate daily summer flow of the entire watershed from Rincon Creek to and including Refugio Creek is less than 4 million gallons per day.

2. This flow is all claimed by riparian owners, water companies, and individual water claims.

3. Storage-reservoir sites of sufficient capacity and elevation do not exist along the streams, if at all. The construction of numerous small reservoirs would increase the operating expenses and also the first cost of construction.

4. Diverting dams in the streams would be necessary to turn the winter flow, and the conduits leading to the storage reservoirs would necessarily be large and expensive.

5. It is very doubtful if the city of Santa Barbara could establish a claim on the waters of these streams which would enable her to obtain them through legal process. Where it is possible to do so, however, the city can not afford to appropriate water which, if not now needed, soon will be, for the supply of the rapidly increasing population of the Carpinteria and Montecito valleys on the east and the Goleta and Dos Pueblos on the west.

STREAMS NORTH OF COAST RANGE.

Having failed to find an adequate supply of water on the south side of the range, the investigations of Wright were extended to the north side of the range, into the basin of Santa Ynez River. Surveys to determine relative elevations were made, and detailed reports on two reservoir sites, one known as the Juncal, near the head of the Santa Ynez, and the other as the Main River reservoir site, below the mouth of Blue Canyon. A general view of the basin of Santa Ynez River is shown in Pl. III, *B*.

From a study of the rainfall data available at the time of his report Wright concludes that it will be necessary to have a storage reservoir capable of holding water from years of average or excessive rainfall for years of deficient rainfall. He believes that in some winters there will be little, if any, storm water in these streams. From April, 1876, to October, 1877, inclusive, there was a period of drought of nineteen months in which the rainfall was insufficient to much more than supply evaporation. On his basis of 200 gallons per day per capita, for a population of 20,000, requiring 4 million gallons per day, this would call for a storage of 2,280 million gallons, which is equal to 7,000 acre-feet of water, an acre-foot being the volume of water sufficient to cover 1 acre 1 foot deep, or 43,560 cubic feet.

JUNCAL RESERVOIR SITE.

The Juncal reservoir site was determined to have the following capacities with the heights of dam stated:

TABLE 3.—*Capacities of Juncal reservoir with various heights of dam.*

Height of dam in feet.	Capacity in gallons.	Capacity in acre-feet.
200	4,000,000,000	12,276
175	2,352,000,000	7,218
150	1,877,000,000	5,760
125	1,437,000,000	4,410
100	1,050,000,000	3,222
75	705,000,000	2,164
50	350,000,000	1,074

A dam 200 feet high would be 550 feet long on top, and one 100 feet high would be 272 feet long on top. Purslow in his report estimates that a dam at the Juncal 100 feet high, with a diversion conduit to Santa Barbara, would cost $300,000. The area of the drainage basin is given as 23.5 square miles by both Wright and Purslow. From the topographic surveys of the United States

A. MONO CREEK DAM SITE AND GAGING STATION.

B. SANTA YNEZ BASIN ON PROJECTED LOCATION OF OLD CITY TUNNEL.

Geological Survey it is found that they were seriously in error, and that there is but 13.4 square miles of area naturally tributary to this reservoir site. This directly affects the value of the Juncal as a storage reservoir. Wright gives certain figures showing that, in his judgment, the water supply would be always sufficient to meet the demands upon this reservoir. At the time the reports of both Wright and Purslow were written little available data existed indicating the flow that might be expected from drainage basins on the Pacific coast, particularly in southern California. Estimates were therefore based upon observations on eastern streams. Since that

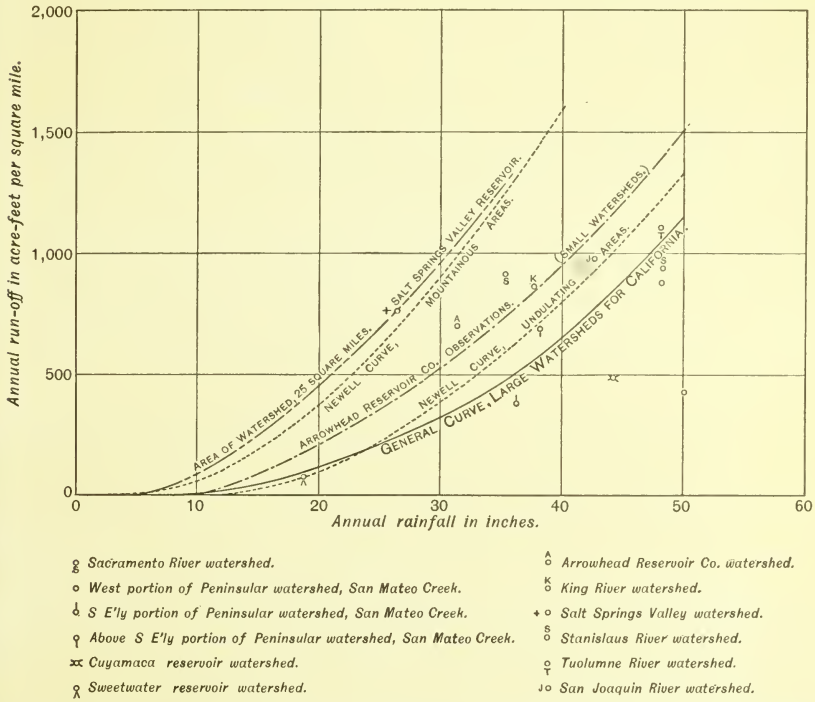

FIG. 1.—Diagram showing relation of rainfall to run-off for California streams. (For description see page 50.)

time, however, the United States Geological Survey has been measuring California streams and determining drainage areas and their rainfall, and there is now better information available on this subject. The whole trend of these late stream measurements has been to show that estimates of run-off for southern California, particularly those based on observations on eastern rivers which were previously considered as comparable, give excessive and unreliable results. While it is impossible to predict accurately what the discharge from any given drainage basin will be, nevertheless, from examinations made of the basin of the Santa Ynez and the application of average conditions observed in localities somewhat

similar and of a mountainous character, it is possible to form an approximately correct idea of the true results. Table 12 shows the estimated run-off from the drainage basin of the Juncal and neighboring streams in detail. From an extended comparison of rainfall data it is believed by the writer that the precipitation on average years in the basin of the Santa Ynez may possibly reach 22 inches. But since late records indicate less rainfall, the Santa Barbara mean of 16.78 is used by the author as the basis of his estimates in table 12 (p. 53). Wright considers that it will be over 20 inches throughout the drainage basin, and Purslow that it will be 27 inches. The rainfall in the mountains varies in the same ratio for wet and dry years as the rainfall at Santa Barbara city. The first rains are absorbed by the ground and retained in the soil until evaporated either from the surface or by the growing plants. It takes about 9 inches of rain to meet these demands, and, generally speaking, no material stream flow will result from a winter's rain unless it exceeds this amount, provided all of this precipitation does not occur in hard successive storms, in which event there would be run-off; usually, however, there will be no stream flow unless the winter rain exceeds 9 inches. When these demands of evaporation are met, the succeeding storms furnish more and more of a water supply for the streams, and the per cent of rain so discharged increases in a growing ratio.

From the studies above referred to, assuming a rainfall of 25 inches in this basin, it is concluded that during the year 1897–98, when the rainfall at Santa Barbara amounted to 4.99 inches, there would have been no high-water stream flow in the mountains. In 1898–99 there would have been available at the Juncal reservoir 1,114 acre-feet; in 1899–1900, 1,367 acre-feet. This is a three-year mean of 827 acre-feet, which would yield a supply of but 730,000 gallons per day, evaporation not being deducted. These figures, compared with Wright's estimated necessary supply of 4,422 acre-feet annually to meet future conditions reasonably within sight (20,000 people), show that the Juncal reservoir site and drainage basin would be inadequate to meet the demands of the city of Santa Barbara. The conclusion of Wright or of Purslow that the Juncal alone is a suitable source for a water supply for the city can not be accepted, although it may be used properly as a supplemental reservoir for hold-over purposes, its waters being liberated at such periods as may be necessary to make up for deficiencies in reservoir sites lower on the stream. In conclusion Mr. Wright makes the following statement:

I consider the Santa Ynez River above the mouth of Blue Canyon to be not only an available source of supply, but the only source possible for the future supply of Santa Barbara with an abundance of good potable water, for the following reasons:

1. Not only the sources of the streams but the entire river are uncontaminated by any of the organic wastes pertaining to civilization, and from the rugged nature of the country are likely to remain so. The sandstone gathering-grounds are of the best class for delivering water free from mineral impurities.

2. The elevation and capacity of the storage sites and the extent of the catchment insure an ample supply of water in all seasons.

3. The riparian rights in that portion of the stream sought to be appropriated are merely nominal, as none of the summer flow above Blue Canyon ever appears on the surface as far down as the San Marcos rancho. The only riparian owner is therefore the owner of the Los Prietos y Najalayegua rancho.[a] This right can probably be purchased, or if not, can be condemned by legal process.

4. The expansive capacity of the district for increasing the supply to meet all possible demands is ample and in excess. This feature alone, other things being equal, should decide in favor of this source of supply.

5. Storage reservoir sites are numerous and ample. The fall of the stream being comparatively light, renders it practicable to arrest the entire flow to the extent required by the demand.

6. The expense of constructing a thoroughly efficient and permanent system of works is no greater than would be the cost of works of equal capacity on the coast side, and maintenance will be much less.

I also recommend the construction of the works as a whole. Omitting the storage reservoir is simply gambling on our good luck, viz, that we will not have a dry season this year or next, and so on until we do get a dry year, when it will be too late to save ourselves from great discomfort and possible pecuniary loss.

REPORT OF E. J. S. PURSLOW, 1896.

Mr. Ernest J. S. Purslow, deceased, a civil engineer, living in Santa Barbara at the time and employed by the Santa Barbara Water Company, investigated in 1896 the same questions covered by Wright's report of 1889. As engineer for the water company, he would naturally have a point of view somewhat different from that of the representative of the city.

Purslow states that the present Santa Barbara Water Company, which consolidated the water rights on Mission Canyon and the De la Guerra wells, was incorporated in January, 1889. This was done in order to increase the available water supply then obtained from Mission Creek by a gravity system of diversion, and from tne De la Guerra wells, located in the city limits, by a pumping system.

NEEDS OF DISTRICT.

Purslow says:

The present water supply is so inadequate and incomplete that it is a physical impossibility for the city to increase in size or population, or for the surrounding country to advance in development, until water is procured from a source other than those in the immediate vicinity, which are now all used to their fullest capacity. The scarcity of water is the first impression that visitors receive, and many who have desired to make this their home have abandoned the idea owing to the gravity of this drawback.

[a] On December 22, 1903, this ranch was included in the Santa Barbara Forest Reserve, lien scrip having been issued to the owners for it.

By the general introduction of meters and the most economical type of service taps the supply of 130 gallons should be ample for all purposes; at which rate the immediate demand of the present population would be about 1 million gallons per diem. The total supply at present, during the dry months of a year with average rainfall, is about 600,000 gallons per diem, about half from the Mission streams and half from the De la Guerra wells.

Nothing has retarded the advance of the city so much as the condition of the water supply, and nothing will promote its future prosperity and growth as much as a remedy for this condition. The present demands of the city being upwards of 1 million gallons per diem, a system could not be considered adequate which will not have a capacity to supply at least 1,500,000 gallons per diem as soon as work can be constructed, with means for subsequently increasing the supply with the growth of the city.

The suburbs of Santa Barbara, and the land extending easterly and westerly from the city, are improved only to the extent to which the waters of the small mountain streams have been made available, principally at points adjacent to and riparian on these streams. West of the city, where small quantities of water are obtained, the land is devoted principally to horticulture, and where water is not obtainable it is used as grazing and farming land. East of the city lies the famed district of El Montecito, which is inhabited, to the extent to which the small streams can supply water, by a class of people who for the most part have independent means, many of whom have built substantial and handsome houses and beautified their grounds, and among whom there are enough people of intellectual pursuits and tastes to form a nucleus which makes it especially attractive for that class of people. It is primarily and distinctively a residence district. Consisting of a gentle slope from the foothills toward the channel, broken and diversified by the natural watercourses, which, though bereft of water during the summer months, are lined with natural timber growth, backed and protected on the north by the Santa Ynez Mountains, nearly every spot commanding a comprehensive and magnificent view of the channel and coast line and the distant islands, possessing the most equable climate in the world and everything else which Almighty God could give except plenty of water, it is destined to become one of the garden spots of the world.

Land which has water is sold at from $500 to $1,000 an acre, and although land has very little productive value without water, such dry land is held and readily sold in El Montecito district at from $250 to $500 an acre. In spite of the unprecedented business depression of the past two years, sales of this land have been made during this period of some 40 tracts scattered through this district, aggregating some 670 acres, at an average price of about $330 an acre. There is no other residence district in California where prices for bare, dry, suburban or agricultural land have been so maintained and sales so extensively made during the past two years. El Montecito comprises about 4,500 acres of land susceptible of irrigation, only a small fraction of which is supplied with water for more than domestic purposes. The duty of water here for full-bearing lemon orchards has been found to be one miner's inch to 10 acres of land with the average soil, a miner's inch being equivalent to a continuous flow of 12,960 gallons per diem. Many lemon orchards have been planted during the past two years on tracts of land which have appurtenant to them such small allowances of water that it is feared that the trees will die before reaching full maturity. When orchard trees are young and small a very small quantity of water suffices to moisten the soil immediately surrounding them; but, as they increase in size and their roots extend, it is necessary to use water enough to irrigate the whole orchard surface. The owners of such orchards will be compelled to purchase more water or see their years of labor end in failure. Ornamental grounds, vegetables, oranges, and other fruits require about the same quantity of water as lemons.[a]

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[a] The tunnel line from the lower reservoir sites on the Santa Ynez (see p. 41) will command all the lands of El Montecito as well as of the city of Santa Barbara. The elevation of the south portal of the present city tunnel is 1,393 feet above sea level. The new tunnel line proposed through Mission Canyon will be at an elevation of 1,186.46 feet (Geological Survey datum).

POSSIBLE SUPPLY.

Purslow then proceeds to show that the proper and adequate solution of the water problem for Santa Barbara and vicinity consists of the storage of the storm waters of Santa Ynez River and their diversion by means of tunnel lines to the south side of the range. He states that there are three available sites for storage reservoirs on lands owned by the water company on the Santa Ynez—one in Blue Canyon, which he afterwards condemns as an impracticable proposition because of its expense and small drainage area; one on the main river near the confluence of the Blue Canyon with the Santa Ynez, which he names the Main River reservoir site, and which has a large storage capacity; and a third, the Juncal reservoir site, near the headwaters of the stream.

BLUE CANYON SITE.

He states that the Blue Canyon site is located at an elevation of 1,500 feet above sea level, with a drainage area of only about 8 square miles. A contour survey which he made showed that a dam 100 feet high above the bed of the gorge would impound 1,500 million gallons, equivalent to 4,600 acre-feet. He admits that the local drainage naturally tributary is totally inadequate to fill this reservoir. It would require a tunnel 10,550 feet long to connect this reservoir with the south side of the mountains.

MAIN RIVER SITE.

In describing the Main River reservoir site he said: "This is one of the best in California"; certainly a very singular statement for an engineer to make, in view of the fact that the width of the dam site on the bed of the creek is 427 feet. He says the drainage area tributary to the Main River reservoir site is 150 square miles, ranging in elevation from 1,500 to 6,000 feet, with a mean rainfall of 30 inches in the drainage basins and a probable minimum of 7 inches. From the recent official surveys of the United States Geological Survey it has been definitely determined that the drainage area above this reservoir site is 71 square miles. The elevation of the bed of the canyon at the Main River dam site is 1,460 feet above sea level. This reservoir site is of such elevation as to command by gravity the present city tunnel line, which may be extended as the outlet for the Mono reservoir site (see pp. 40–41). The Main River reservoir site is owned by the Santa Barbara Water Company and is of some merit. If a tunnel is carried through the range this reservoir, commanding the present city tunnel in elevation, may ultimately be built, either by the water company or by its successors, thus materially adding to the supply for the district south of the mountains, which demands all the water possible to be obtained from Santa Ynez River.

JUNCAL SITE.

Purslow states that an observer was stationed at the Juncal, recording the rainfall and taking measurements of the flow of the stream during the "past winter," and that these records show that up to the date of writing the flow available for storage was upwards of 800 million gallons (2,455 acre-feet). This quantity includes the flow of Alder Creek basin (2.4 square miles), which he proposed to divert into the Juncal. It can not be definitely stated what space of time he meant to include within this period, but as his report bears date July 21, 1896, it is probable that these measurements extend from the 1st of November, 1895, to say the 1st of July, 1896. The rainfall during that winter was 13.77 inches at Santa Barbara, and his conclusion can not be accepted that this record may be taken as an approximate minimum for streams in the Santa Ynez Mountains, particularly as there was at Santa Barbara in the month of January a precipitation of 6.84 inches, which should, in all probability, have yielded a flood condition in the streams.

Purslow's surveys of the capacity of the Juncal reservoir site practically confirm those by Wright, already stated. The site is one of considerable merit, and possibly the dam should be built ultimately in connection with supplementing the storage capacity of the lower dams. The Gibraltar reservoir site, below the Mono on the trunk stream, however, offers a very much cheaper storage capacity and a much larger available supply. Purslow probably overestimates the underflow at the Main River site.

Purslow proposes using a riveted-steel pressure pipe line to divert the water to Santa Barbara; probably the life of this pipe line would not be more than fifteen years. His detailed estimate of the cost is $300,000 to obtain water from the Juncal. The dam which he proposes is to be 100 feet high, with a storage capacity of 1,023 million gallons. He estimates the minimum season's supply as 400 million gallons, and considers an annual draft of 600 million gallons (equal to 1,845 acre-feet) as the amount that might be obtained from the reservoir with that dam.

It is here estimated that the run-off from the Juncal would have been in minimum years as follows:

Run-off from Juncal reservoir.

	Acre-feet.
1869–70	603
1870–71	335
1897–98	0
1898–99	1,114
1899–1900	1,367

It must be remembered that these estimates are only approximations based upon observations on other streams somewhat similarly

situated and are not absolute. However, they are believed to be fair conclusions from the best available data, and, using them, we can not accept the conclusion that 1,845 acre-feet of water could annually be withdrawn from this reservoir site. This, however, does not condemn the site, if it is used in connection with the lower site to supplement the supply in dry years. It is believed that ultimately this reservoir may be constructed for this purpose, but it is not believed that it is wise to base a water supply for the city of Santa Barbara on it alone with its drainage basin of but 13 square miles.

REPORT OF R. B. CANFIELD, 1896.

On July 28, 1896, Mr. R. B. Canfield, president of the Santa Barbara Water Company, made a report supplemental to that of Purslow. Mr. Canfield's conclusions are also of interest because of his intimate and accurate knowledge of the water situation near Santa Barbara, on the south of the Santa Ynez Mountains. It must be remembered that the measurements of Wright to which he refers were made in a year of excessive stream flow.

Canfield says:

Mr. Wright found all the streams east of Santa Barbara, together with Mission Creek—9 streams in all—to be yielding daily 1,650,000 gallons, and the 15 creeks west of Mission Creek, to and including the Refugio, to be yielding daily 1,725,000 gallons, but he justly dismisses the idea of obtaining the needed supply from these sources as impracticable, partly owing to the expense of gathering and conveying the supply from so many points and over so long distances, and partly owing to the fact that all this water is claimed by riparian owners and individual water claimants and water companies organized to supply districts adjacent to some of the streams. It is well known that the demand for this water, especially in the neighborhood of this city, is beyond the capacity of all the streams to supply, and it is obvious that the expense of obtaining water from these sources would be prohibitive.

All the streams (excepting the flow of the Hot Springs) on the south slope of the range east of Mission Creek as far as Romero Canyon, 8 miles distant, were yielding when measured in the summer of 1889 a total daily flow of 500,000 gallons, while the creeks west of Mission Canyon to and including San Jose Creek, 7 miles distant, were yielding a total daily flow of only 475,000 gallons, notwithstanding the comparatively abundant rainfall of preceding seasons. Even though these were the minimum quantities to be obtained in the dry season from these streams (which is far from being the case) and it were possible to bring them all to Santa Barbara for the supply of the city, whether by surface diversion or by means of tunnels in their neighborhood, which would intercept the supplies and drain their channels, it would not be desirable to do so. Santa Barbara, if she could afford the expense necessary for the acquisition of these waters, could not afford the loss she would suffer by the destruction of the prosperity and beauty of her suburbs of Montecito and Goleta. The prosperity of Santa Barbara depends in a large measure upon that of the neighboring rural districts, as does theirs upon that of the city. To the extent to which the city deprives the suburbs of their natural water supply, it injures itself.

During the last spring borings were made under the direction of the city engineer west of the city in the hope of finding considerable underground currents, but without success. The subterranean waters in the eastern part of the ctiy are tapped by the wells of the Santa Barbara Water Company for the supply of its pumping plant; but all efforts to obtain the large additional supply which the city needs from these and other sources have

only tended to confirm the soundness of Mr. Wright's conclusion when he said: "I consider Santa Ynez River above the mouth of Blue Canyon to be not only an available source of supply, but the only source possible for the future supply of Santa Barbara with an abundance of good potable water."

Water is now sold in Santa Barbara at the rate of about 16 cents per thousand gallons to the city for street-sprinkling purposes (at the rate of $35,000 per year for 1 second-foot) and to private consumers at from 20 to 25 cents per thousand gallons, which are moderate rates as compared with those realized in some other cities in this State; and it is believed that although the development of the business in the future may justify some reduction of rates, an average rate of 15 cents per thousand gallons at least can be calculated upon. The city requires for its immediate needs at least 1,000,000 gallons of water daily, and its steady growth, soon to be accelerated by the completion of the railroad to San Francisco, will be constantly increasing this demand.

REPORT OF J. LINN MOYER, 1902.

MONO SITE.

On August 5, 1902, Mr. J. Linn Moyer, city engineer of Santa Barbara, made a report based on a reconnaissance through portions of the drainage basin of Santa Ynez River, particularly examining a new reservoir site suggested by Mr. Frank E. Kellogg, which the latter had observed on Mono Creek, the largest tributary of the upper portion of Santa Ynez River. Moyer made a favorable report on this situation, based on this reconnaissance, and made recommendations that further examinations be made. It was his judgment that the reservoir site, which is called the Mono site, was a good one and that the water supply available would be ample to meet the necessities of the city. Pls. III, *A*, and IV, *A*, *B*, show views of the Mono dam and reservoir sites. He recommended as follows:

1. That the exact elevation of the dam site be determined in order to ascertain whether or not the water could be conducted to the city tunnel.
2. That borings and excavations be made on the dam site to ascertain the depth of bed rock and the quality of same.
3. That a topographical survey be made of the reservoir basin in order to determine the height necessary to construct the dam, and also to determine the amount and location of land necessary to be purchased.
4. That an option be obtained on the land necessary to be purchased, as will be shown by the topographical survey.
5. That a chemical analysis be made of the waters of Mono Creek.
6. That the grade of the present city tunnel be reduced to the lowest possible rate.

Moyer found that a provision should be made to furnish a continuous supply of 1 million gallons per day in addition to the present flow of the tunnel in order to fully supply the entire present population of the city.

CONCLUSIONS DRAWN FROM FOREGOING REPORTS.

The foregoing reports have been reviewed in extenso because doing so brings these investigations up to date and also because they furnish a proper basis from which to start on the present investigations. It

A. MONO DAM SITE, LEFT ABUTMENT.

B. MONO CREEK RESERVOIR SITE.

View upstream from dam site.

will be seen that all of these distinguished authorities, each one of whom was intimately acquainted with the local situation, agree on the following vital points:

1. That the present supply of water for the city of Santa Barbara is inadequate and that unless it is increased the material development of the town will be seriously impeded.

2. That there is no adequate water supply within a reasonable limit of the city of Santa Barbara on the south side of the range from which the city could be supplied, and even if the water of such small streams as there are could be obtained it would be at a sacrifice of existing development.

3. That it is feasible and desirable to obtain an adequate supply of water from the drainage basin of Santa Ynez River, and that this can be done at a profit.

The writer has, therefore, taken up the consideration of the subject at this point and prepared estimates of cost, etc.

POPULATION AND CONSUMPTION OF WATER.

The population of Santa Barbara, according to the enumeration of the United States Census, is as follows:

Population of Santa Barbara.

1870	2,889
1880	3,460
1890	5,864
1900	6,587
1905 (estimated)	10,000
1910 (estimated)	12,500

The rate of growth of Santa Barbara was most rapid from 1880 to 1890, but it has always shown a substantial increase in population. Projecting it into the future we obtain the populations for 1905 and 1910 as stated above. It is believed by the other engineers, as well as the writer, that the development of the city is largely dependent upon an adequate water supply, not only in the city but upon the adjacent suburban property. If this is once obtained it may be expected that the population will more rapidly increase. Among people looking for future homes, especially in the West, the water question is considered one of prime importance in the selection of a residence. At present (1903) the municipal waterworks has some 709 taps through which water is served, and the Santa Barbara Water Company has about 900, making a total of 1,609 taps, serving a population of about 8,045 persons. The Gates system supplies 50 taps more.

In May, 1902, 301 meters of the municipal waterworks indicated 81 gallons per capita daily consumption. In June, 1902, 329 meters

indicated a consumption of 82 gallons per capita. In July, 1902, 369 meters indicated a consumption of 75.5 gallons per capita per day.

It will be seen that 55 per cent of the city's services are metered. It is estimated that 15 gallons per capita per day, not included in the above rate, are used in public buildings and in street sprinkling. It would probably be fair to say, using round numbers, that the present consumption of the city is 100 gallons per capita per day. This is a rather low rate of consumption for a California city, and in all probability the city would use to advantage more water if it were available at reasonable prices. The consumption in Los Angeles before meters were introduced, in the summer of 1901, was 306 gallons per capita per day. After the introduction of several thousand meters it is now 242 gallons per capita per day. The water commissioners of that city in their annual report for 1902 estimate that a reasonable consumption would be 150 gallons per capita per day for metered services. The city of San Jose, in 1890, was using 194 gallons per capita daily. Wright, in his report to the city, estimated on a consumption of 200 gallons, and Purslow considered that 130 gallons should be sufficient.

Considering the evidence in the case, it is believed that it is desirable, for the proper development of the city, improvements of lawns, gardens, etc., that 150 gallons daily, as an average for the year, should be used, and this has been adopted as a proper basis for this report.

In considering the storage of flood waters necessary to meet this situation, it has been estimated that 60 per cent of the water supply would be used in the six summer months, and 40 per cent in the six winter months. The question of evaporation from reservoirs is an important one in estimating on a storage system. It is believed that the annual evaporation from reservoirs in the basin of the Santa Ynez would be approximately 42 inches in depth, 67½ per cent of this occurring in the six summer months, and 32½ per cent in the six winter months. From a study of the monthly rainfall tables of precipitation occurring at Santa Barbara (see table 11) it appears that there would, in all probability, have been no material addition to the waters stored in any reservoirs in this locality from May 1, 1876, to December 1, 1877, a period of nineteen months. Again, between April 1, 1897, and October 1, 1898, or for a period of eighteen months, there would have been no material addition. It will be necessary, therefore, in order to prepare for the worst condition that will probably occur in the future, as judged by a record of thirty-six years' rainfall in the past, to construct reservoirs that will hold a supply of water for a period of nineteen months of continuous withdrawal without replenishment.

With a population of 10,000 persons in 1905, reasonably within sight and necessary to immediately prepare for, at 150 gallons per

day, there will be a consumption of 1,500,000 gallons daily. This amount of water withdrawn for a period of nineteen months will require 2,826[a] acre-feet for actual domestic uses. It is also necessary to provide for a loss by evaporation of about 692 acre-feet (for a reservoir of this size for nineteen months), or a total of 3,518 acre-feet for use and evaporation during the worst period of drought that the city will probably ever have to face.

Reducing it to a monthly withdrawal, there will be required for summer use 170 acre-feet, for summer evaporation about 45 acre-feet, and for summer use and evaporation 215 acre-feet.

From surveys that have been made of the reservoirs, described later in this report, it appears that a dam 85 feet high at the Mono site, impounding water to a depth of 75 feet, will give storage capacity for 3,880 acre-feet of water—enough to meet the above needs, even assuming the severe conclusions that no permanent supply can be relied upon from the tunnel, and that the municipality is to furnish all the water for the town. Similarly a dam 100 feet high at the Gibraltar site (see p. 55) would give an equal capacity and have tributary thereto a larger and better water supply.

NEAR-BY SUPPLIES.

The question of local water supply on the south side of the range was extensively discussed under the review of the reports of Wright, Purslow, and Canfield. Generally speaking, the amount now available for the city may be taken in average years as 300,000 gallons daily from Mission Creek, 300,000 gallons from the De la Guerra wells (statement by Purslow), and 350,000 gallons from the city tunnel, making 950,000 gallons to meet an estimated normal present demand of 1,200,000[b] gallons, or a deficit daily of 250,000 gallons.

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[a] One acre-foot is equivalent to 325,851 gallons.

[b] On basis of 150 gallons per day for 8,000 persons.

MISSION CREEK.

The following measurements of Mission Creek taken at various times, as stated, may be of interest in this connection:

TABLE 4.—*Discharge measurements on Mission Creek.*

Date.	Hydrographer.	Discharge in second-feet.[a]	Gallons per day.
1888.			
Jan. 15	A. Poett	0.93	605,594
24	do	2.80	18,200,000
Feb. 7	do	1.37	888,552
Mar. 16	do	2.23	1,452,000
July 26	do	.36	233,000
29	do	.28	184,747
1889.			
July 13	do	.43	282,609
17	do	.36	232,551
Aug.	G. F. Wright	.34	219,672
18	A. Poett	.21	137,052
Sept. 1	do	.32	206,821
1892.			
June 11	do	.36	232,673
1894.			
June 28	Flourney	.24	155,115
1900.			
May 10	do	.25	161,600
June 17	L. Moyer	.045	[b] 29,084

[a] One second-foot is equivalent to 50 miner's inches.
[b] Above diversion not on bed rock, 200 feet above dam.

TABLE 5.—*Measurements in Mission Canyon.*

[50 miner's inches=1 cubic foot per second.]

AT NOTCHED WEIR NEAR PORTAL OF PROPOSED NEW CITY MISSION TUNNEL.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Aug. 14	2.30 p. m.	R. L. North and J. Compton	6.367
15	8.30 a. m.	do	9.474
15	9 a. m.	do	8.817
15	9.30 a. m.	do	8.817
15	10 a. m.	do	8.689
15	10.30 a. m.	do	8.140

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT NOTCHED WEIR NEAR PORTAL OF PROPOSED NEW CITY MISSION TUNNEL—C't'd.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Aug. 15	11 a. m.	R. L. North and J. Compton	7.823
15	11.30 a. m.	do	7.832
15	12 m.	do	7.242
15	12.30 p. m.	do	6.959
15	1 p. m.	do	6.363
15	1.30 p. m.	do	6.109
15	2 p. m.	do	5.600
15	2.30 p. m.	do	5.359
15	3. p. m.	do	5.220
15	3.30 p. m.	do	4.851
15	4 p. m.	do	4.851
15	4.30 p. m.	do	4.851
15	5 p. m.	do	5.042
AT OLD MISSION DAM.			
1903.			
Aug. 22	6.30 p. m.	L. M. Hyde and R. L. North	0.909
23	9.10 a. m.	do	4.762
24	8.25 a. m.	L. M. Hyde, R. L. North, and G. D. Morrison	8.333
24	6.15 p. m.	do	6.896
25	7.45 a. m.	L. M. Hyde and R. L. North	10.000
27	7.15 a. m.	R. L. North, R. F. Wyckoff, and G. D. Morrison	10.000
AT NOTCHED WEIR AS ABOVE.			
1903.			
Aug. 27	8.30 a. m.	R. L. North and R. F. Wyckoff	9.080
27	9 a. m.	do	9.080
27	1 p. m.	do	7.070
27	1.30 p. m.	do	6.420
27	2 p. m.	do	5.750
27	2.30 p. m.	do	5.750
27	3 p. m.	do	5.410
27	3.30 p. m.	do	4.950
27	4 p. m.	do	4.990
27	4.30 p. m.	do	4.990
27	5 p. m.	do	4.810

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT OLD MISSION DAM.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Oct. 3	2.20 p. m.	J. L. Moyer, T. B. Curley, and D. Boyle	5.320

AT NOTCHED WEIR AS ABOVE.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Oct. 19	8 a. m.	L. M. Hyde and C. M. Elliott	7.532
19	8.30 a. m.	do	7.356
19	9 a. m.	do	6.742
19	9.30 a. m.	do	6.314
19	10 a. m.	do	6.158
19	10.30 a. m.	do	6.003
19	11 a. m.	do	6.003
19	11.30 a. m.	do	5.803
19	12 m.	do	5.600
19	12.30 p. m.	do	5.317
19	1 p. m.	do	5.042
19	1.30 p. m.	do	4.810
19	2 p. m.	do	4.591
19	2.30 p. m.	C. M. Elliott	4.591
19	3 p. m.	do	4.378
19	3.30 p. m.	do	4.255
19	4 p. m.	do	4.169
19	4.30 p. m.	do	4.169
19	5 p. m.	do	3.970
Nov. 4	8.30 a. m.	G. D. Morrison	8.817
4	9 a. m.	do	8.753
4	9.30 a. m.	do	7.708
4	10 a. m.	do	7.416
4	10.30 a. m.	do	7.187
4	11 a. m.	do	6.852
4	11.30 a. m.	do	6.792
4	12 m.	do	6.579
4	12.30 p. m.	do	6.579
4	1 p. m.	do	6.261
4	1.30 p. m.	do	6.003
4	2 p. m.	do	6.003
4	2.30 p. m.	do	5.853
4	3 p. m.	do	5.903
4	3.30 p. m.	do	5.600

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT NOTCHED WEIR AS ABOVE—Continued.

Date.		Time.	Hydrographer.	Discharge in inches.
1903.				
Nov.	4	4 p. m.	G. D. Morrison	5.750
	4	4.30 p. m.	do	5.600
	16	8.30 a. m.	R. F. Wyckoff	8.689
	16	9 a. m.	do	7.945
	16	9.30 a. m.	do	7.299
	16	10 a. m.	do	7.242
	16	10.30 a. m.	do	6.595
	16	11 a. m.	do	6.792
	16	11.30 a. m.	do	6.687
	16	12 m.	do	6.420
	16	12.30 p. m.	do	6.314
	16	1 p. m.	do	6.314
	16	1.30 p. m.	do	5.853
	16	2 p. m.	do	5.600
	16	2.30 p. m.	do	5.269
	16	3 p. m.	do	5.131
	16	3.30 p. m.	do	4.950
	16	4 p. m.	do	4.851
	16	4.30 p. m.	do	4.680
	28	8.30 a. m.	R. L. North	6.370
	28	9 a. m.	do	6.690
	28	9.30 a. m.	do	6.000
	28	10 a. m.	do	5.900
	28	10.30 a. m.	do	5.650
	28	11 a. m.	do	5.650
	28	11.30 a. m.	do	5.510
	28	12 m.	do	5.510
	28	1 p. m.	do	5.040
	28	1.30 p. m.	do	4.850
	28	2 p. m.	do	4.720
	28	2.30 p. m.	do	4.680
	28	3 p. m.	do	4.680
	28	3.30 p. m.	do	4.340
	28	4 p. m.	do	4.300
	28	4.30 p. m.	do	4.130
	28	5 p. m.	do	3.970
Dec.	24	10.30 a. m.	G. D. Morrison	7.470
	24	11 a. m.	do	6.560
	24	11.30 a. m.	do	6.370

TABLE 5.—*Measurements in Mission Canyon*—Continued.

AT NOTCHED WEIR AS ABOVE—Continued.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Dec. 24	12 m.	G. D. Morrison	6.210
24	12.30 p. m.	do	6.160
24	1 p. m.	do	6.160
24	1.30 p. m.	do	5.950
24	2 p. m.	do	5.600
24	2.30 p. m.	do	5.460
24	3 p. m.	do	5.320
24	3.30 p. m.	do	5.080
24	4 p. m.	do	5.040
1904.			
Feb. 29	11.15 a. m.	L. M. Hyde	18.190
Mar. 14	3.30 p. m.	do	16.310

AT OLD MISSION DAM.

1904.			
Apr. 4		L. M. Hyde	16.670

TABLE 6.—*Measurements in Rattlesnake Canyon.*

AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY.

[50 miner's inches=1 cubic foot per second.]

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Aug. 17	8.30 a. m.	R. L. North and J. Compton	2.507
17	9 a. m.	do	2.596
17	9.30 a. m.	do	2.507
17	10 a. m.	do	2.216
17	10.30 a. m.	do	2.216
17	11 a. m.	do	2.216
17	11.30 a. m.	do	2.261
17	12 m.	do	2.261
17	12.30 p. m.	do	2.216
17	1 p. m.	do	2.261
17	1.30 p. m.	do	2.216
17	2 p. m.	do	2.216

TABLE 6.—*Measurements in Rattlesnake Canyon*—Continued.

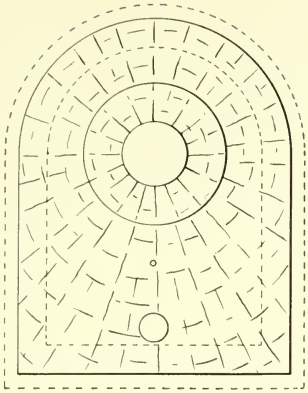
AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY—Continued.

Date.		Time.	Hydrographer.	Discharge in inches.
1903.				
Aug.	17	2.30 p. m.	R. L. North and J. Compton	2.132
	17	3 p. m.	do	2.080
	17	3.30 p. m.	do	2.080
	17	4 p. m.	do	2.080
	17	4.30 p. m.	do	2.080
	17	5 p. m.	do	2.216
Oct.	3	3.45 p. m.	J. L. Moyer, T. B. Curley, and D. Boyle	2.261
	19	8.30 a. m.	R. L. North	1.772
	19	9 a. m.	do	1.627
	19	9.30 a. m.	do	1.492
	19	10 a. m.	do	1.582
	19	10.30 a. m.	do	1.471
	19	11 a. m.	do	1.582
	19	11.30 a. m.	do	1.582
	19	12 m.	do	1.302
	19	12.30 p. m.	do	1.448
	19	1 p. m.	do	1.403
	19	1.30 p. m.	do	1.242
	19	2 p. m.	do	1.471
	19	2.30 p. m.	do	1.302
	19	3 p. m.	do	1.262
	19	3.30 p. m.	do	1.403
	19	4 p. m.	do	1.514
	19	4.30 p. m.	do	1.448
	19	5 p. m.	do	1.514
Nov.	3	9.30 a. m.	G. D. Morrison	1.871
	3	10 a. m.	do	1.847
	3	10.30 a. m.	do	1.897
	3	11 a. m.	do	1.822
	3	11.30 a. m.	do	1.797
	3	12 m.	do	1.797
	3	12.30 p. m.	do	1.746
	3	1 p. m.	do	1.772
	3	1.30 p. m.	do	1.772
	3	2 p. m.	do	1.651
	3	2.30 p. m.	do	1.746
	3	3 p. m.	do	1.722
	3	3.30 p. m.	do	1.722
	3	4 p. m.	do	1.772

TABLE 6.—*Measurements in Rattlesnake Canyon*—Continued.

AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY—Continued.

Date.		Time.	Hydrographer.	Discharge in inches.
1902.				
Nov.	3	4.30 p. m.	G. D. Morrison	1.772
	15	9 a. m.	R. F. Wyckoff	2.360
	15	9.30 a. m.	do	2.360
	15	10 a. m.	do	2.272
	15	10.30 a. m.	do	2.160
	15	11 a. m.	do	2.160
	15	11.30 a. m.	do	2.132
	15	12 m.	do	2.132
	15	12.30 p. m.	do	2.080
	15	1 p. m.	do	2.080
	15	1.30 p. m.	do	2.080
	15	2 p. m.	do	1.972
	15	2.30 p. m.	do	2.051
	15	3 p. m.	do	2.080
	15	3.30 p. m.	do	2.051
	15	4 p. m.	do	2.051
	15	4.30 p. m.	do	2.080
	28	8.30 a. m.	G. D. Morrison	2.160
	28	9 a. m.	do	2.110
	28	9.30 a. m.	do	2.030
	28	10 a. m.	do	2.050
	28	10.30 a. m.	do	2.000
	28	11 a. m.	do	1.950
	28	11.30 a. m.	do	1.950
	28	12 m.	do	1.900
	28	12.30 p. m.	do	1.950
	28	1 p. m.	do	1.900
	28	1.30 p. m.	do	1.850
	28	2 p. m.	do	1.820
	28	2.30 p. m.	do	1.820
	28	3 p. m.	do	1.770
	28	3.30 p. m.	do	1.720
	28	4 p. m.	do	1.750
Dec.	23	9 a. m.	do	2.510
	23	9.30 a. m.	do	2.510
	23	10 a. m.	do	2.480
	23	10.30 a. m.	do	2.480
	23	11 a. m.	do	2.390
	23	11.30 a. m.	do	2.360



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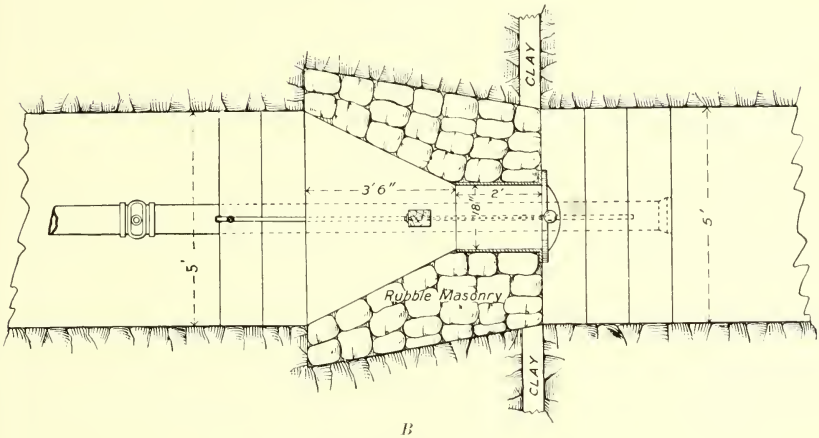

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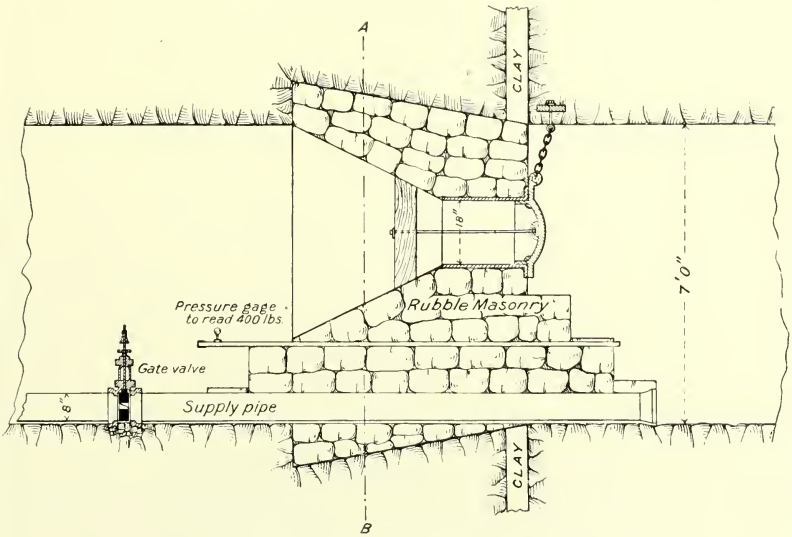

C

BULKHEAD AND DISCHARGE PIPES IN OLD CITY TUNNEL, COLD SPRINGS CANYON.

A, End view; *B*, plan; *C*, longitudinal section.

TABLE 6.—*Measurements in Rattlesnake Canyon*—Continued.

AT NOTCHED WEIR ABOUT 200 FEET UPSTREAM FROM WHERE WATER IS DIVERTED FOR SANTA BARBARA WATER SUPPLY—Continued.

Date.	Time.	Hydrographer.	Discharge in inches.
1903.			
Dec. 23	12 m.	G. D. Morrison	2.360
23	12.30 p. m.	do	2.270
23	1 p. m.	do	2.270
23	1.30 p. m.	do	2.330
23	2 p. m.	do	2.360
23	2.30 p. m.	do	2.360
23	3 p. m.	do	2.360
23	3.30 p. m.	do	2.390
23	4 p. m.	do	2.450
1904.			
Apr. 7	1.45 p. m.	L. M. Hyde	12.460

DE LA GUERRA WELLS.

At the De la Guerra pumping station there are seven cased wells from 200 to 700 feet deep. These discharge into a concrete well 25 feet in diameter and 30 feet deep, having a capacity of 110,160 gallons. This well fills during the night and is pumped out during the day. If the wells are considered as discharging as much during the day as they do during the night when the tank is filling, their flow at present is about 220,000 gallons daily and is (in 1903) decreasing. As the pumps run more than twelve hours each day the output is correspondingly greater. There is installed at this station one Prescott pump of 1½ million gallons nominal capacity and one Worthington pump of 1 million gallons capacity daily. The pumps discharge directly into the city mains and work against a pressure head of from 100 to 120 pounds. Mr. Wright states that in August, 1889, a six-day test of these wells indicated a capacity of 600,000 gallons daily. It is stated that these wells afterwards failed and that deeper wells were then sunk, from which the present supply is now obtained.

CITY TUNNEL.

In the month of January, 1896, the city of Santa Barbara started a tunnel for the development of water in sec. 36, T. 5 N., R. 26 W., San Bernardino meridian. The tunnel has been successful in this particular and has been of inestimable service to the city in sustaining it through the period of intense drought of the last few years. The tunnel is 7 feet high and 5 feet wide at the base. The elevation of

the portal is approximately 1,400 feet above sea level, and it was driven for the first 4,800 feet of its length on a grade of 1 foot in 100. The purpose in running the tunnel at first was solely to develop water and not with the intention of extending it on through the mountains. It will be noted from the table of discharge that during its construction the discharge was surprisingly constant, irrespective of length. Enough water is thus obtained for a number of consumers, but not enough to supply a large town or city. The amount of water which was extracted from the mountain was sufficient to pay for the cost of the excavation. It is quite possible that in years of ordinary rainfall the unregulated flow of water from the tunnel would have been more constant, but the years of construction were ones of unusual drought. However, from the fact that the water supply has not been materially increased by lengthening the tunnel, and that the flow of the water pays for the cost of the work, it has been a natural and logical sequence that the city should contemplate the extension of this or some other tunnel entirely through the Coast Range into the drainage basin of the Santa Ynez in order to make available the water of this large mountainous area. The tunnel work has been carried on with intelligence, the power from the water coming therefrom being conducted through pressure pipes and used for the running of drills for the excavation work.

COST OF TUNNEL.

As a guide to what the city may expect in the future, the expense of doing this tunnel work is of interest. It will be noted that there has been variation in the cost, owing to local conditions of the labor market, etc. The city has installed the machinery necessary for doing the work, and the contractor has furnished the labor and material necessary for its prosecution at the rate named in the table.

TABLE 7.—*Cost of labor and material in driving city tunnel.*

Distance excavated.	Price per foot.	Distance excavated.	Price per foot.
Feet.		*Feet.*	
0 to 1,000	$5.50	1,642 to 1,750	.....
1,000 to 1,146	7.50	1,750 to 1,786½	$13.76
1,146 to 1,202	8.73	1,786½ to 2,286	9.30
1,202 to 1,276½	7.58	2,286 to 2,572	10.00
1,276½ to 1,363½	6.89	2,572 to 3,072	10.75
1,363½ to 1,434½	8.25	3,072 to 3,572	10.48
1,434½ to 1,500	9.00	3,572 to 4,072	9.17
1,500 to 1,582	.....	4,072 to 5,072	9.00
1,582 to 1,642	9.00		

DISCHARGE OF TUNNEL.

The tunnel is run in a sandstone and shale formation characteristic of the Coast Range, the rock being considerably broken and somewhat stratified. As the work progresses many crevices and cavities in the rock filled with water, probably from rainfall, are found, and as the tunnel cuts the various lines of cleavage these underground reservoirs are tapped. The actual rock is not of a very porous nature and in itself does not yield much water, but it is believed that these cavities will be refilled, at least in part, by subsequent rains and that a material amount of water can be permanently withdrawn from the tunnel. If the city does obtain a supply therefrom permanently there will be just that much more water at its disposal, and there certainly is a market for it all, either in the city or on adjoining agricultural lands.

The water is led from the tunnel to two city reservoirs, each with a capacity of 1,600,000 gallons, situated at an elevation of 350 feet above the city datum plane.

The power now available at the tunnel for driving the drills and blowers is inadequate for its continuation. Generally speaking, it requires from 10 to 12 horsepower to run each air drill, not including the power for the blowers for ventilation.

In order to regulate the flow of water from this tunnel after the last contract was finished, to the 5,000-foot point from the heading, a bulkhead was designed by the author and placed in the tunnel about 800 feet from the portal. During the winter of 1902–3 there was a fair amount of rainfall and the streams were capable during that time of meeting the demands of the city. As soon as the bulkhead could be closed this was done—about July 1, 1903.

Because of the fissured condition of the rock in the tunnel it was not feasible at the point where the bulkhead was first placed to completely close the supply from the heading, as springs occurred below the bulkhead toward the portal, flowing in considerable volume. However, the pressure ran up to 49 pounds to the square inch on July 25, as recorded by the pressure gage placed in the discharge pipe, indicating an accumulated head of water back of the bulkhead of 114 feet. This shows that the tunnel was developed into a storage reservoir. The gate valve in the bulkhead was gradually opened as the season progessed, and the supply maintained a flow of from 24 to 33 miner's inches during the remainder of the summer. On October 17, when the valve was completely opened and the pressure had been reduced to zero, the flow had fallen to 24 miner's inches. This was sufficient to carry the city through the summer successfully.

During the winter of 1903–4 a new bulkhead was placed at a point in the tunnel where a heavy clay seam occurs in the rock. This new bulkhead was more effective than the first one constructed in

holding back the water. It is hoped that this will form an impervious barrier against the passage of the ground water, thus enabling the tunnel to accumulate a high head of water.[a]

Table 8a shows the variation in volume discharged from the tunnel, as well as the pressure in pounds per square inch, as the season advances.

TABLE 8.—*Flow of water from city tunnel.*

Date.	Length of tunnel in feet.	Flow in miner's inches.[b]	Flow in gallons per day.
1900.			
May 1	2,952	25.00	323,125
July 26	3,078	19.00	245,575
August 1	3,103	19.00	245,575
October 27	3,267	20.00	258,500
November 4	3,280	25.00	323,125
1901.			
January 9	3,393	38.00	491,150
February 1	3,448	50.00	646,250
February 28	3,561	63.33	818,583
April 1	3,614	55.00	710,875
May 1	3,680	45.00	581,625
June 1	3,740	45.00	581,625
July 1	3,792	[c]35.00	452,375
August 1	3,865	30.00	387,750
1902.			
February 4	4,182	30.00	387,750
March 4	4,256	30.00	387,750
March 31	4,309	33.00	426,525
April 29	4,367	30.00	387,750
June 7	4,509	24.00	310,200
July 25	4,560	25.50	329,588
August 4	4,578	27.75	358,669
September 2	4,647	30.30	391,628
December 1	4,832	30.00	387,750

[a] 24.59 inches of rain fell at Montecito between September 24, 1904, and March 3, 1905, and the pressure on the tunnel bulkhead had increased to 80 pounds per square inch.
[b] 50 miner's inches are equivalent to 1 second-foot, and 1 miner's inch to 12,925 gallons per day.
[c] Estimated.

TABLE 8a.—*Daily mean head over 18-inch weir, and discharge, of Santa Barbara tunnel, 1903.*[a]

Day	January.				February.				March.				April.			
	Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.		
		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.
1	0.191	0.405	20.25	261,758	0.210	0.469	23.45	303,122	0.271	0.679	33.95	438.848	0.292	0.756	37.80	488,614
2	.193	.412	20.60	266,282	.214	.482	24.10	311,524	.270	.675	33.75	436,263	.326	.890	44.50	575,220
3	.195	.418	20.90	270,160	.218	.493	24.65	318,633	.270	.675	33.75	436,263	.370	1.068	53.40	690,264
4	.195	.418	20.90	270,160	.217	.489	24.45	316,048	.269	.971	33.55	433,677	.371	1.072	53.60	692,850
5	.195	.418	20.90	270,160	.214	.482	24.10	311,524	.269	.671	33.55	433,677	.369	1.064	53.20	687,679
6	.195	.418	20.90	270,160	.210	.469	23.45	303,122	.268	.668	33.40	431,738	.365	1.046	52.30	676,045
7	.195	.418	20.90	270,160	.214	.482	24.10	311,524	.268	.668	33.40	431,738	.361	1.032	51.60	666,997
8	.195	.418	20.90	270,160	.220	.500	25.00	323,158	.267	.664	33.20	429,153	.357	1.016	50.80	656,656
9	.195	.418	20.90	270,160	.227	.524	26.20	338,669	.267	.664	33.20	429,153	.354	1.003	50.15	648,254
10	.195	.418	20.90	270,160	.235	.553	27.65	357,412	.266	.660	33.00	426,568	.352	.995	49.75	643,083
11	.195	.418	20.90	270,160	.234	.549	27.45	354,827	.266	.660	33.00	426,568	.350	.986	49.30	637,267
12	.200	.435	21.75	281,147	.231	.538	26.90	347,717	.265	.656	32.80	423,983	.346	.969	48.45	626,279
13	.204	.448	22.40	289,549	.228	.528	26.40	341,254	.265	.656	32.80	423,983	.344	.961	48.05	621,109
14	.200	.435	21.75	281,147	.232	.542	27.10	350,303	.264	.653	32.65	422,044	.342	.954	47.70	616,585
15	.200	.435	21.75	281,147	.238	.560	28.00	361,936	.264	.653	32.65	422,044	.340	.947	47.35	612,060
16	.200	.435	21.75	281,147	.246	.589	29.45	380,680	.263	.650	32.50	420,105	.338	.940	47.00	607,536
17	.200	.435	21.75	281,147	.254	.618	30.90	399,423	.263	.650	32.50	420,105	.341	.944	47.20	610,121
18	.200	.435	21.75	281,147	.247	.592	29.60	382,618	.264	.653	32.65	422,044	.350	.986	49.30	637,267
19	.202	.442	22.10	285,671	.240	.567	28.35	366,461	.264	.653	32.65	422,044	.350	.986	49.30	637,267
20	.204	.448	22.40	289,549	.240	.567	28.35	366,461	.266	.660	33.00	426,568	.350	.986	49.30	637,267
21	.205	.452	22.60	292,134	.249	.600	30.00	387,789	.266	.660	33.00	426,568	.350	.986	49.30	637,267
22	.205	.452	22.60	292,134	.256	.626	31.30	404,593	.265	.656	32.80	423,983	.350	.986	49.30	637,267
23	.205	.452	22.60	292,134	.257	.630	31.50	407,178	.265	.656	32.80	423,983	.350	.986	49.30	637,267
24	.205	.452	22.60	292,134	.261	.645	32.25	416,873	.263	.650	32.50	420,105	.350	.986	49.30	637,267
25	.205	.452	22.60	292,134	.259	.637	31.85	411,703	.262	.647	32.35	418,166	.350	.986	49.30	637,267
26	.207	.459	22.95	296,659	.258	.633	31.65	409,117	.262	.647	32.35	418,166	.350	.986	49.30	637,267
27	.210	.469	23.45	303,122	.257	.630	31.50	407,178	.262	.647	32.35	418,166	.349	.982	49.10	634,681
28	.214	.482	24.10	311,524	.265	.656	32.80	423,983	.266	.660	33.00	426,568	.351	.990	49.50	639,852
29	.212	.476	23.80	307,646	.....	.....	.....	.....	.268	.668	33.40	431,738	.350	.986	49.30	637,267
30	.209	.465	23.25	300,536	.....	.....	.....	.....	.269	.671	33.55	433,677	.348	.978	48.90	632,096
31	.207	.459	22.95	296,659	.....	.....	.....	.....	.278	.706	35.30	456,298	.....	.....	.....	.....
Total	.....	.....	.....	8,787,947	.....	.....	.....	10,114,830	.....	.....	.....	13,253,984	.....	.....	.....	19,035,918
Average	.201	.439	21.93	283,482	.237	.559	27.95	361,244	.266	.662	33.08	427,548	.349	.982	49.09	634,531

[a] By the closing of the bulkhead during the spring of 1904 the water was again impounded in the tunnel and the flow regulated therefrom so as to sustain a fairly constant flow throughout the summer of 1904. Owing to the drought this was the main water supply of the city during that period.

TABLE 8a.—*Daily mean head over 18-inch weir, and discharge, of Santa Barbara tunnel, 1903*—Continued.

Day.	May.				June.				July.				August.			
	Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.		
		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.
1	0.354	1.003	50.15	648,254	0.302	0.796	39.80	514,467	0.326	0.890	44.50	575,220	0.307	0.816	40.80	527,393
2	.360	1.029	51.45	665,058	.300	.788	39.40	509,269	.326	.890	44.50	575,220	.318	.857	42.85	553,892
3	.362	1.036	51.80	669,582	.301	.792	39.60	511,881	.326	.890	44.50	575,220	.320	.865	43.25	559,062
4	.362	1.036	51.80	669,582	.302	.796	39.80	514,467	.326	.890	44.50	575,220	.326	.890	44.50	575,220
5	.358	1.021	51.05	659,888	.302	.796	39.80	514,467	.326	.890	44.50	575,220	.329	.902	45.10	582,976
6	.360	1.029	51.45	665,058	.300	.788	39.40	509,269	.300	.788	39.40	509,296	.329	.902	45.10	582,976
7	.363	1.039	51.95	671,521	.300	.788	39.40	509,269	.239	.563	28.15	363,875	.336	.932	46.60	602,366
8	.366	1.050	52.50	678,631	.300	.788	39.40	509,269	.225	.518	25.90	334,791	.333	.919	45.95	593,963
9	.366	1.050	52.50	678,631	.298	.780	39.00	504,126	.220	.500	25.00	323,158	.322	.873	43.65	564,233
10	.360	1.029	51.45	665,058	.292	.756	37.80	488,614	.220	.500	25.00	323,158	.321	.869	43.45	561,648
11	.360	1.029	51.45	665,058	.293	.760	38.00	491,199	.219	.496	24.80	320,572	.328	.898	44.90	580,391
12	.360	1.029	51.45	665,058	.278	.706	35.30	456,298	.219	.496	24.80	320,572	.290	.748	37.40	483,444
13	.358	1.021	51.05	659,888	.306	.812	40.60	524,808	.220	.500	25.00	323,158	.249	.600	30.00	387,789
14	.308	.820	41.00	529,978	.307	.816	40.80	527,393	.220	.500	25.00	323,158	.273	.687	34.35	444,018
15	.223	.510	25.50	329,621	.308	.820	41.00	529,978	.234	.549	27.45	354,827	.275	.694	34.70	448,543
16	.258	.633	31.65	409,117	.310	.828	41.40	535,149	.270	.675	33.75	436,263	.277	.702	35.10	453,713
17	.300	.788	39.40	509,296	.311	.832	41.60	537,734	.292	.756	37.80	488,614	.276	.698	34.90	451,128
18	.301	.792	39.60	511,881	.312	.836	41.80	540,319	.268	.668	33.40	431,738	.275	.694	34.70	448,543
19	.302	.796	39.80	514,467	.313	.840	42.00	542,905	.254	.618	30.90	399,423	.274	.690	34.50	445,957
20	.303	.800	40.00	517,052	.314	.843	42.15	544,844	.258	.633	31.65	409,117	.273	.687	34.35	444,018
21	.304	.804	40.20	519,637	.315	.847	42.35	547,429	.272	.683	34.15	441,433	.270	.675	33.75	436,263
22	.305	.808	40.40	522,223	.316	.850	42.50	549,368	.271	.679	33.95	438,848	.300	.788	39.40	509,296
23	.307	.816	40.80	527,393	.317	.853	42.65	551,307	.267	.664	33.20	429,153	.324	.881	44.05	569,404
24	.308	.820	41.00	529,978	.318	.857	42.85	553,892	.272	.683	34.15	441,433	.254	.618	30.90	399,423
25	.307	.816	40.80	527,393	.319	.861	43.05	556,477	.275	.694	34.70	448,543	.134	.241	12.05	155,762
26	.307	.816	40.80	527,393	.320	.865	43.25	559,062	.274	.690	34.50	445,957	.194	.415	20.75	268,221
27	.306	.812	40.60	524,808	.321	.869	43.45	561,648	.271	.679	33.95	438,848	.277	.702	35.10	453,713
28	.306	.812	40.60	524,808	.322	.873	43.65	564,233	.276	.698	34.90	451,128	.278	.706	35.30	456,298
29	.305	.808	40.40	522,223	.323	.877	43.85	566,818	.264	.653	32.65	422,044	.260	.641	32.05	414,288
30	.303	.800	40.00	517,052	.325	.885	44.25	571,989	.260	.641	32.05	414,288	.258	.633	31.65	409,117
31	.303	.800	40.00	517,052	.....	.....	.....	.....	.274	.690	34.50	445,957	.256	.626	31.30	404,593
Total	.....	.....	.....	17,742,639	.....	.....	.....	15,898,056	.....	.....	.....	13,355,452	.....	.....	.....	14,767,561
Average	.324	.886	44.28	572,342	.308	.820	41.00	529,935	.267	.667	33.33	430,821	.285	.737	36.85	476,373

Day.	September.				October.				November.				December.			
	Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.			Mean head over weir.	Discharge.		
		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.		Second-feet.	Miner's inches.	Gallons for 24 hours.
1	0.254	0.618	30.90	399,423	0.240	0.567	28.35	366,461	0.228	0.528	26.40	341,254	0.223	0.510	25.50	329,621
2	.252	.612	30.60	395,545	.238	.561	28.05	362,583	.228	.528	26.40	341,254	.222	.507	25.35	327,682
3	.250	.604	30.20	390,374	.260	.641	32.05	414,288	.228	.528	26.40	341,254	.222	.507	25.35	327,682
4	.250	.604	30.20	390,374	.276	.698	34.90	451,128	.228	.528	26.40	341,254	.222	.507	25.35	327,682
5	.248	.596	29.80	385,204	.260	.641	32.05	414,288	.228	.528	26.40	341,254	.222	.507	25.35	327,682
6	.248	.596	29.80	385,204	.250	.604	30.20	390,374	.228	.528	26.40	341,254	.222	.507	25.35	327,682
7	.248	.596	29.80	385,204	.244	.581	29.05	375,509	.228	.528	26.40	341,254	.222	.507	25.35	327,682
8	.248	.596	29.80	385,204	.241	.570	28.50	368,400	.228	.528	26.40	341,254	.222	.507	25.35	327,682
9	.248	.596	29.80	385,204	.240	.567	28.35	366,461	.228	.528	26.40	341,254	.222	.507	25.35	327,682
10	.248	.596	29.80	385,204	.260	.641	32.05	414,288	.227	.524	26.20	338,669	.222	.507	25.35	327,682
11	.248	.596	29.80	385,204	.244	.581	29.05	375,509	.227	.524	26.20	338,669	.222	.507	25.35	327,682
12	.248	.596	29.80	385,204	.241	.570	28.50	368,400	.227	.524	26.20	338,669	.222	.507	25.35	327,682
13	.248	.596	29.80	385,204	.240	.567	28.35	366,461	.227	.524	26.20	338,669	.222	.507	25.35	327,682
14	.247	.592	29.80	382,618	.239	.563	28.15	363,875	.227	.524	26.20	338,669	.222	.507	25.35	327,682
15	.246	.589	29.45	380,680	.238	.560	28.00	361,936	.227	.524	26.20	338,669	.222	.507	25.35	327,682
16	.246	.589	29.45	380,680	.236	.556	27.80	359,351	.227	.524	26.20	338,669	.221	.503	25.15	325,096
17	.245	.585	29.25	378,094	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.221	.503	25.15	325,096
18	.244	.581	29.05	375,509	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.221	.503	25.15	325,096
19	.243	.577	28.85	372,924	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.221	.503	25.15	325,096
20	.242	.574	28.70	370,985	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.220	.500	25.00	323,158
21	.240	.567	28.35	366,461	.235	.553	27.65	357,412	.227	.524	26.20	338,669	.220	.500	25.00	323,158
22	.269	.671	33.55	433,677	.236	.556	27.80	359,351	.227	.524	26.20	338,669	.220	.500	25.00	323,158
23	.262	.647	32.35	418,166	.236	.556	27.80	359,351	.226	.520	26.00	336,084	.220	.500	25.00	323,158
24	.260	.641	32.05	414,288	.236	.556	27.80	359,351	.225	.517	25.85	334,145	.220	.500	25.00	323,158
25	.259	.637	31.85	411,703	.234	.549	27.45	354,827	.225	.517	25.85	334,145	.220	.500	25.00	323,158
26	.221	.503	25.15	325,096	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.220	.500	25.00	323,158
27	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.220	.500	25.00	323,158
28	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.219	.496	24.80	320,572
29	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.224	.514	25.70	332,206	.219	.496	24.80	320,572
30	.240	.567	28.35	366,461	.232	.542	27.10	350,303	.223	.510	25.50	329,621	.218	.493	24.65	318,633
31	.....	.....	.....	.....	.230	.535	26.75	345,779	.....	.....	.....	.....	.218	.493	24.65	318,633
Total	.....	.....	.....	11,519,277	.....	.....	.....	11,436,546	.....	.....	.....	10,136,802	.....	.....	.....	10,081,227
Average	.247	.594	29.70	383,976	.241	.571	28.55	368,921	.227	.523	26.15	337,893	.221	.503	25.15	325,201

TOTAL NEAR-BY SUPPLY.

Reviewing these measurements we have a probable summer minimum water supply available for the city from local sources approximately as follows:

Local water supply of Santa Barbara.

	Gals. per day.
Minimum from Mission Creek	100,000
Minimum from De la Guerra wells	300,000
Minimum from city tunnel	300,000
Total	700,000

as against an estimated normal summer demand of 1,200,000[a] gallons per day, or an estimated normal deficit daily of 500,000 gallons.

There is not as much water now being used in the city for beautifying lawns and gardens as would be so applied if a more abundant supply were available. From the above it is evident that the city should take immediate steps toward increasing its water supply.

DISTANT SUPPLIES.

EXTENSION OF CITY TUNNEL.

With a view to the extension of the present city tunnel through the Santa Ynez Range to tap the waters of Santa Ynez River, a system of triangulation was carried across the mountains from Santa Barbara to the Mono reservoir site by Homer Hamlin and W. B. Clapp, of the Geological Survey. The base line of this system was measured on State street, Santa Barbara, between Boulevard and Pedregosa streets, and the most northerly point was the high peaks south of the Mono reservoir site. The base line, which was carefully measured with a 300-foot steel tape under a uniform tension of 25 pounds and corrected for temperature, was 9,753.7 feet long. The angles were measured with a Berger transit No. 1b, circles 6¼ inches in diameter. Eleven principal triangulation stations and 5 secondary stations were occupied, the secondary triangulation being necessary to reach the south portal of the present city tunnel, which is situated in a deep canyon. Angles were repeated three times and measured in six sets of two each. The triangles closed for angles within 0° 0′ 0″ to 0° 0′ 10″. The angle adjustments were made by distributing the difference proportionally as probable error due to weather conditions. The traverse of the outside boundary of the triangulation system closed as follows: N., 45,343.66; S., 45,343.63; E., 28,397.22; W., 28,397.15.

[a] On basis of 150 gallons per day for 8,000 persons.

The north portal of the extended tunnel, as projected, was fixed by a station on the cliff on the south side of Santa Ynez River. The north portal bears N. 26° 38′ 18″ E., and is 18,842.06 feet distant from the south portal of the present city tunnel. This tunnel was 4,895 feet long on January 26, and if an angle is made in it at 5,960 feet it will be necessary to drive 15,006 feet to reach Santa Ynez River and finish the work. By doing so a saving of 1,475 feet will be made; otherwise the tunnel must have a length of 21,376 feet to get through the range. It is probable, however, that a still more favorable location may be found.

From the surveys that have been made during the last season in the drainage basin of Santa Ynez River, the elevation of the south portal of the city tunnel in Cold Spring Canyon was taken at 1,393.06 feet; the rise on grade from the portal to station 48, at the projected north portal, is 49.02 feet. The total length of excavation necessary to complete this tunnel through the range is 15,066 feet. At a grade of 0.1 per cent this will require 15 feet more to be consumed in tunnel grade, making the elevation of the north portal of the tunnel 1,457.18 feet. The elevation of Santa Ynez River bed opposite is 1,425 feet. The necessary grade to be consumed from the north portal of the tunnel to the Mono reservoir site would be about 4 feet, making the elevation of the grade at the Mono reservoir site 1,461.18 feet. The elevation of the bed of the creek at the Mono site is 1,440 feet, so that the conduit grade would be 21.18 feet above the bed of the creek at that point, but the capacity of the lower portion of a reservoir site is always very small, and there would be a loss of but 1 per cent in the capacity of a 100-foot dam at the Mono with the elevations given.

CONSTRUCTION OF NEW TUNNEL.

In the old city tunnel in Cold Spring Canyon several angles occur in the alignment. The grade of the tunnel is also not satisfactory, in that it is too high to reach the bed of the stream at the mouth of the Mono at the elevation of the creek. While the old city tunnel could be used in this regard, it is not considered the best site for a tunnel, in view of subsequent surveys and investigations. Moreover, the old tunnel is delivering a very substantial water supply under existing conditions, particularly since being regulated by the bulkhead described above, and as a new tunnel can be obtained at a satisfactory elevation, which will develop a new water supply and in addition command certain reservoir sites on lower portions of the stream below the mouth of the Mono, it is desirable to adopt the second location. After the first investigations made in the basin of Santa Ynez River, which included the survey of the Mono reservoir site, the Main River reservoir site, and an inspection of

sites higher on the stream, a much better site situated on the main stream below the mouth of the Mono was found. This is called the Gibraltar reservoir site and is described more fully below.

The capacity of the Gibraltar reservoir so not quite so great as that of the Mono, but is very satisfactory, while the dam site is very much better, and the tributary drainage area a great deal larger, including not only that of the Mono, but also that of the Santa Ynez above the Mono, and 17 square miles of Main Canyon below. For the season of 1902–3 the measured flow at the Mono dam site was 8,934 acre-feet, at the Santa Ynez above the Mono 9,898 acre-feet, and for the Santa Ynez at the Gibraltar reservoir site 21,202 acre-feet. As the water supply is the most essential feature of the entire enterprise, no hesitation is felt in recommending that the tunnel line which is to be run through the range should be made to command the Gibraltar reservoir site. This would be impossible with the old city tunnel, on account of its high elevation in Cold Spring Canyon. Moreover, the combined cost of the Gibraltar dam and of a tunnel to it from Mission Canyon is less than the combined cost for completing the old city tunnel and building the Mono dam.

For the reasons given above, the triangulation which had been made for the old city tunnel was extended so as to cover the site of a possible new tunnel line from Mission Canyon to the Gibraltar dam site, which would be 19,560 feet long and would run through the same general formation at right angles to the line of the strike of the rock, passing under portions of Mission Creek.

AGREEMENT WITH WATER COMPANY.

An agreement was made with the Santa Barbara Water Company for rights of way for this new tunnel line. This company has for years been acquiring lands along Mission Canyon in order to protect its water supply, which comes mostly therefrom. The company naturally felt that the running of the tunnel beneath Mission Creek might affect its supply of water from the creek and insisted on being secured against such a contingency. In consequence the Santa Barbara water commissioners entered into a contract with the company, by which the city agrees to maintain the supply of the company at 14 inches from July 1 to December 31 and at 22 inches from January 1 to June 30, supplying the water from the tunnel in case it is not flowing naturally in the creek, provided that amount can be supplied from the tunnel alone and irrespective of water subsequently obtained from storage reservoirs. In return the Santa Barbara Water Company gives the city rights of way over all its lands for wagon roads, tunnels, pipe lines, etc., and agrees not to run any tunnels on its lands in the vicinity of the city tunnel. This contract is fully

justified by the physical conditions encountered in the water development. Moreover, the water delivered to the water company will be used in any event in the immediate vicinity of Santa Barbara or for the beautifying and improvement of the town.

A section of the proposed new tunnel is shown in figs. 16 and 17 (pp. 91, 92), the timbered section being used only where necessary and the rock section being the prevailing type for the tunnel.

CONTRACT FOR CONSTRUCTION.

The work of driving the tunnel was divided into two parts, a southern portion of the tunnel to be 11,000 feet long and constructed from the south portal, and a northern portion to be 8,560 feet long and constructed from the north portal. Bids were called for and received, and the contracts awarded to F. J. Smith and E. J. Hunt, of Santa Barbara, for the south part, and to Robert Beyrle, of Los Angeles, for the north part. The prices were as follows:

Successful bids for new Santa Barbara tunnel.

	South division.	North division.
Per cubic yard of excavation	$8.00	$9.00
Overhaul per cubic yard per 100 feet (free haul being 500 feet)	.02	.01½
Timbers in place (per M feet, B. M.)	35.00	45.00

The total cost of the southern portion of the tunnel under the contract will be $109,125, and for the northern portion $90,267, a total of $199,392 for the entire tunnel. The estimate of the author, as consulting engineer for the work, was 19,560 feet of tunnel at $10 a foot, $195,600, plus 10 per cent for contingencies, or a total of $215,160. An additional allowance was made of 5 per cent for engineering expenses.

The yardage excavated in the tunnel is to be limited by the quantity shown on the section. After the completion of the work the contractor is required to leave his track in the tunnel for the purpose of hauling cement through it for the construction of the dam on Santa Ynez River, thus avoiding a wagon haul over the high mountains. The contracts were let in February, 1904.

VENTURA RIVER.

From an examination of the topographic maps of the Geological Survey, which have been recently prepared and which are of inestimable value in a general consideration of this subject, it was found that it would be possible by a gravity line to divert the headwaters of Ventura River from a point near the junction of the main and

north forks of Matilija Creek by gravity through Casitas Pass to Santa Barbara. A reconnaissance was made of this country, and a number of water measurements were made throughout the length of Ventura River. A month of minimum flow was selected as the proper time at which to make these determinations, as the minimum is the controlling condition in all questions involving water supply. There was a rainfall at Santa Barbara for the seasons of 1901–1902 of 14.06 inches. The stream flow during this season, however, was below normal.

TABLE 9.—*Flow measurements on Ventura River and tributaries.*

1902.		Locality.	Inches.
Sept.	25	At Matilija, above North Fork	99
	25	North Fork at mouth	21
		Total, all diverted	120
	25	River bed dry from Matilija School to near Coyote Creek	.....
	25	Below Coyote Creek and below Domestic diversion	14
	25	Head Domestic system's lower ditch	185
	25	Head Domestic system's upper ditch	62
		Total Ventura River below and near Coyote Creek	261
	26	Head of power ditch, below Domestic diversions	75
	26	River bed above and near power house	8
		Total	83
	26	Domestic ditch above and near reservoir	222

WATER AVAILABLE.

It will be noted that all of the water of Matilija Creek at the point from which a gravity line could be started to Santa Barbara is diverted and now in use, and consequently there was on that date no supply available for Santa Barbara at this point. In addition to this, the intervening topography is rugged and the distance would be very great, rendering it impracticable from a commercial standpoint to obtain a supply from this source.

It will also be noted that there were 75 inches of water diverted into the power ditch of the Ventura waterworks, which runs from a point approximately 4 miles north of Ventura to a point approximately 1½ miles north of this city, and that there were 8 inches of water above the point where this power ditch would discharge into the river, making a total of 83 inches in the lower portion of the river that was not diverted for domestic uses. During the daytime, at the time of the inspection, all this 75 inches of water was being used for irrigation, leaving but 8 inches of water in Ventura River

available for surface diversion. Information, however, was given that a portion of the water diverted through the domestic conduits during the daytime is accumulated in a certain domestic reservoir, and that at nighttime, from 11 p. m. until 6 a. m., a discharge of 280 miner's inches from this reservoir ordinarily takes place through the power house for the purpose of developing power and is wasted into the river. This is equivalent to a continuous flow of 82 miner's inches. This water wasted into the sea, taken in connection with the 8 inches flowing in the stream bed above the power house, makes a total of 90 miner's inches of water, which at this time, admitted to be one of drought, might be considered as wasted water and available for sale or disposal by the Ventura Water, Light, and Power Company. In addition to this, it is stated that the 75 inches of water diverted through the power ditch is not permanently sold for irrigation purposes, but is used by irrigators by sufferance on the part of the water company, and that the Ventura Water, Light, and Power Company could sell it to the city of Santa Barbara if it so desired. There thus might be made available from the lower portion of Ventura River a low-water supply of 165 miner's inches (2,145,000 gallons per day), provided all the above assumptions are correct.

The statement was made that there is practically a continuous use of the 30 inches of water from the power ditch during the daytime for irrigation, which might reduce these figures to 135 miner's inches (1,750,000 gallons daily). This is an unusually large amount of water to be available for disposal along this coast, and it was considered to be sufficient to justify a further investigation to determine the cost of its delivery to Santa Barbara.

The elevation at which this water could be obtained is practically 50 feet above sea level, and it would, therefore, have to be pumped to Santa Barbara through a long force main, laid possibly on the railroad right of way, for an aggregate distance of 26.2 miles. There is quite favorable opportunity of obtaining cheap fuel along this line, and a pumping station might be erected at the intake and a sufficient head generated to force the water through the pipe line, delivering it to the city of Santa Barbara at the foot of State street without pressure, in order to avoid the expense of a long pipe line designed to withstand high heads. At this point it would be picked up by a second pumping plant and forced to the high levels of the city. No legal examination of title was made as to the ownership of this water.

COST OF PIPING AND PUMPING.

It may be assumed, therefore, for the sake of estimating, that there is available from the lower Ventura River a supply of water

sufficient to furnish 1,500,000 gallons daily, adequate for 10,000 people using 150 gallons per capita each day. This is equal to 2.32 cubic feet per second, or 116 miner's inches of water. This water would have to be purchased from the Ventura Water, Light, and Power Company, from which no figure has as yet been obtained as to the price for which it would be sold. It is believed that the parties owning this water would be willing to contract for its delivery. If $300 per miner's inch were paid for this water, it would cost the city of Santa Barbara $34,800 at Ventura. An 18-inch continuous wooden stave pipe laid from the Ventura River to the foot of State street would be 138,300 feet in length, or 26.2 miles. The friction head to be overcome by water passing through this length of pipe, when carrying 1,500,000 gallons daily, would be 48.4 feet. It is believed that the average friction and hydraulic head on the pipe would be 50 feet. The pipe would be laid either on country roads or possibly along the railroad right of way. At certain projecting and precipitous cliffs the pipe would have to be run through tunnels. The conduit would be what is technically known as a continuous wooden stave pipe with steel bands, a form of construction which is satisfactory. It would be of a more permanent character than riveted pipe, but not of so enduring a nature as cast-iron pipe. Cast-iron pipe, however, because of its present high cost ($45 a ton delivered at Pacific coast terminals), would be entirely out of the question. The water would be delivered without pressure at the foot of State street, in order to avoid excessive cost due to necessarily stronger pipe required in case a high head was put on it to directly connect with the mains of the city for local distribution. From this point it would have to be lifted to domestic reservoirs. The following table is an estimate on the cost of laying such a pipe line:

TABLE 10. *Estimated cost of Santa Barbara-Ventura pipe line.*

Section.	Length.	Class of excavation.	Cost.	Cost of excavation.	Cost of backfill.	Total cost of trenching.	Cost of pipe.	Total cost.
	Lin. ft.		*Lin. ft.*					
1	7,920	Trench	$0.15274	$1,209.70	$302.42	$1,512.12	$9,504.00	$11,016.12
2	6,864	do	.191	1,311.02	327.75	1,638.77	8,236.80	9,875.57
3	2,640	do	.15274	403.23	100.81	504.04	3,168.00	3,672.04
4	1,584	do	.09546	151.21	37.80	189.01	1,900.80	2,089.81
5	1,320	Tunnel	5.00	6,600.00		6,600.00	1,584.00	8,184.00
6	27,984	Trench	.09546	2,671 35	667.84	3,339.19	33,580.80	36,919.99
7	6,072	Tunnel	5.00	30,360.00		30,360.00	7,286.40	37,646.40
8	7,392	Trench	.09546	705.64	176.41	882.05	8,870.40	9,752.45
9	5,280	Tunnel	5.00	26,400.00		26,400.00	6,336.00	32,736.00
10	9,500	Trench	.17183	1,632.38	408.10	2,040.48	11,400.00	13,440.48
11	61,776	do	.09546	5,897.14	1,474.28	7,371.42	74,131.20	81,502.62
Total	138,332			77,341.67	3,495.41	80,837.08	165,998.40	246,835.48

A portion of the line would be in ground that is quite alkaline. The wooden part of the pipe would not be attacked by the alkali, but the iron rods would be. If we assume a length of life for the pipe of twenty years, and that a sinking fund at 4 per cent interest would necessarily have to be provided to renew it at the end of that time, $8,287.54 would have to be set aside annually to meet the charge. At 4 per cent interest this would capitalize at $207,188, which should properly be added to the first cost of the pipe, giving $454,023 as the real cost of the pipe line to the city. This computation is given in order to compare the real cost of this pipe line with other permanent construction mentioned later.

It would be necessary to install two pumping plants, one at Ventura to force this water through the pipe line against the friction head, and the other to lift the water from the foot of State street to an assumed level of 300 feet to a domestic reservoir. The cost of the first plant would be $9,649, and of the second plant $13,970, or a total of $23,619. If a life of twenty years is assumed for pumping plants also, and provision is made for their renewal by a sinking fund as before, bearing 4 per cent interest, there would have to be set aside each year for this purpose $792.49, which is interest at 4 per cent on $19,802, making a total cost to the city of pumping plants of $43,421.

These pumping plants would be improved and modern triple-expansion condensing steam plants. The first plant would consume 5.5 barrels of crude oil daily, and the second 14.5 barrels of oil daily, or a total of 20 barrels of oil daily to deliver 1½ million gallons daily. This oil at $1 a barrel, which would be a fair price for a long period of use, would represent a daily charge of $20, and an annual charge of $7,300. Attendance of engineers and assistants would probably amount to $5,000 annually; so the oil and attendance together would be $12,300, which, capitalized at 4 per cent, represents $307,500.

To summarize we now have:

Summary of cost of Santa Barbara-Ventura pipe line.

	First cost.	First cost and maintenance.
1,500,000 gallons of water daily	$34,800	$34,800
Pipe line	246,835	454,023
Two pumping plants	23,619	43,421
Fuel and attendance		307,500
Total	305,254	839,744

This figure of first cost and maintenance would represent the real expense to the city of building and maintaining such a plant perpetually,

and on this basis can be properly compared with permanent construction, such as masonry.

This plant would practically be incapable of being increased in capacity without rebuilding the entire system, and no estimates have been included for rights of way.

SANTA YNEZ RIVER.

The county of Santa Barbara, by petition of its board of supervisors, and the city, through its trustees, requested the United States Geological Survey to make topographic surveys and hydrographic investigations in Santa Barbara County to assist in the solution of the difficult water problems which confront this beautiful coast district, often called the American Riviera. As it is the policy of the Geological Survey to carry on its work where the results will be of greatest value, it acceded to this request and has extended its topographic surveys over the greater portion of the county. Pl. I is made up from the results of these surveys. Hydraulic investigations have also been begun, three reservoirs surveyed, several tunnel lines triangulated, and three gaging stations established. It is intended to extend these investigations during the coming season so as to cover the entire drainage basin of Santa Ynez River. To a limited extent the city of Santa Barbara has cooperated financially in the hydraulic work.

Santa Ynez River rises in the mountains of Santa Barbara and Ventura counties, and flows westerly with a flat grade to the Pacific Ocean, having a length of approximately 75 miles. The Santa Ynez Range of mountains, varying in elevation from 3,000 to 4,000 feet, forms the southern boundary of this drainage basin. The northern divide ranges from 4,500 to 5,500 feet, culminating in Mount Pinos, the elevation of which is 8,826 feet. The mean elevation of the basin above the mouth of Mono Creek is 3,500 feet above sea level.

RAINFALL.

The mean rainfall at Santa Barbara is 16.78 inches; at Nordhoff, in Ventura County, at an elevation of 1,200 feet, it is about 18 inches; at Mutau Flat, on the headwaters of Piru Creek, and on the eastern slope of the range, at an elevation of 4,850 feet, it is 19 inches; at Snedden's ranch, on the north fork of the headwaters of the Piru, on the eastern slope of the mountains, at an elevation of 4,900 feet, it is 15 inches; at Cuddy's ranch, at an elevation of 5,000 feet, in Kern County, near the head of Tejon Creek, it is 20 inches, and at Old Fort Tejon, at an elevation of 3,245 feet, it is 18 inches. These records, except those of Santa Barbara, which were begun in 1867, are of rather short duration and fragmentary. The mean rainfall given for each mountain station is determined by finding the ratio of precipitation at Santa

Barbara for the years during which rainfall was observed at the high point in question, and the mean of the 37-year record at Santa Barbara, and applying that ratio to the observed rainfall at the mountain station. There are no known observations of rainfall in the upper portion of the Santa Ynez.

It is well known by the people living along the Pacific coast that the rainfall increases as the slope of the mountain ranges exposed to the sea breezes is ascended. Usually this increase amounts to six-tenths of an inch of rain for each 100 feet rise in elevation, which increase is to be added to the observed precipitation at the base of the range. On the eastern slope of the mountain ranges, on the side away from the ocean, this estimate does not at all hold, there being an actual diminution of rainfall after passing a crest. Consequently it is to be expected that such stations as Mutau Flat and Snedden's ranch, situated easterly from the main crest of the Coast Range, will have less precipitation than occurs on the exposed westerly side of the range. The Santa Ynez Range undoubtedly abstracts a portion of the moisture of the clouds that are passing inland over the drainage basin of Santa Ynez River, but the precipitation must again increase on the westerly sides of the high Coast Range on the northerly and easterly portions of the drainage basin, where the mountains rise from 2,000 to 3,000 feet higher than the summits of the Santa Ynez Mountains.

Mr. Purslow says that the rainfall in the basin of the Santa Ynez above the reservoir sites which he examined is 30 inches, and Mr. Wright states that in his judgment it is over 20 inches. Mr. Marsden Manson, civil engineer of the California Water and Forest Association, prepared a rainfall map, showing precipitation throughout the State, on which he estimates the rainfall in this district as between 20 and 30 inches. Mr. William Hammond Hall, when State engineer of California, also prepared a rainfall map, showing the precipitation for this district to be between 20 and 30 inches. Lieutenant Glassford, of the United States Signal Service, in 1891 officially estimated the rainfall on the headwaters of the Santa Ynez at from 20 to 25 inches.

After a careful examination of the drainage basin, of the vegetation covering it, of available rainfall records, and from a general knowledge of the precipitation throughout this portion of the State, the writer believes that the average rainfall in this basin is about 22 inches. However, in order to be within safe limits in making the estimates of available water supply, the same rainfall is used for computing the run-off of the Santa Ynez basin as has been observed at Santa Barbara.

RUN-OFF.

The question of determining the relation of what is called run-off (or the amount of water the streams discharge) to rainfall is one of considerable difficulty and uncertainty. It is dependent upon the character of the rains, whether gentle showers or violent storms (the latter yielding the greater run-off), and also upon the steepness of the slopes and the size of the watershed. Other things being equal, the small watershed has the higher percentage of run-off. A one or two years' record does not establish a final ratio.

The forest cover of the drainage basin also greatly affects the run-off. If it is a denuded area the floods are more violent and shorter in duration and the summer stream is much lower. If the drainage basin has a proper forest or brush cover the stream is more uniform in flow and carries less silt. The general porosity of the soil and rock also affects the character of the run-off.

A number of efforts have been made to establish this ratio of rainfall to run-off. The diagram presented herewith as fig. 1 (p. 15) shows by curved lines on a horizontal scale the amount of rainfall in inches of depth, and on the vertical scale the total corresponding volume of water discharged in acre-feet, an acre-foot of water being the amount that will cover 1 acre 1 foot deep, or 43,560 cubic feet. The curve which is used in this report is one that has been determined as the result of a large number of measurements in California made by the United States Geological Survey. It will be noted that it indicates less run-off than the others.

The Salt Springs Valley reservoir is in Calaveras County, Cal., in the foothills. The Newell curve for "mountainous areas" is a general determination, by Mr. F. H. Newell, hydrographer of the Geological Survey, for the high mountain areas of the western portions of the United States. The Arrowhead reservoir is in San Bernardino County, Cal. The Newell curve for "undulating areas" is the relation determined by Mr. Newell for hill countries. The general curve for large watersheds for California is the one used in this report as the result of California observations made largely during the drought period through which we have passed. It will be noted that there is no run-off indicated until after the rainfall exceeds 10 inches. All of these curves are much more unfavorable to large run-off than has customarily been accepted for eastern streams.

TABLE 11.—*Record of precipitation at Santa Barbara, Cal.*

[Latitude, 34° 25′; longitude, 119° 40′. Elevation, 100 feet. Authority, War Department and Weather Bureau.]

Year.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Total.
1867–68	0.00	0.00	2.31	12.67	3.97	2.00	1.08	2.44	0.72	0.00	0.00	0.00	25.19
1868–69	.00	.00	1.25	4.26	3.26	2.12	4.22	.46	.20	.00	.00	.00	15.77
1869–70	.00	.30	.65	.57	.25	5.87	.83	.99	.74	.07	.00	.00	10.27
1870–71	.00	1.04	.27	1.41	.86	2.92	.02	2.02	.37	.00	.00	.00	8.91
1871–72	.00	.09	1.83	6.56	2.53	1.81	.18	1.80	.00	.14	.00	.02	14.96
1872–73	.05	.00	.00	4.34	.58	5.48	.05	.00	.00	.00	.00	.00	10.50
1873–74	.00	.00	.27	5.26	4.54	3.17	.78	.28	.14	.00	.00	.00	14.44
1874–75	.00	1.91	1.30	.00	14.84	.18	.38	.10	.00	.00	.00	.00	18.71
1875–76	.00	.00	6.53	.31	7.56	5.67	2.73	.27	.00	.00	.00	.00	23.07
1876–77	.00	.32	.00	.00	2.72	.00	.82	.18	.45	.00	.00	.00	4.49
1877–78	.00	.00	1.32	3.12	7.17	11.73	2.47	3.34	.29	.07	.00	.00	29.51
1878–79	.00	.32	.00	5.16	5.24	.71	.34	1.60	.21	.00	.00	.00	13.58
1879–80	.00	.41	1.62	4.57	1.30	10.86	1.15	5.73	.00	.00	.00	.00	25.64
1880–81	.00	.25	.28	9.73	2.83	.30	1.25	.59	.00	.00	.00	.00	15.23
1881–82	.44	1.47	.33	.95	1.13	2.38	5.74	1.63	.00	.20	.00	.00	14.27
1882–83	.00	.37	.77	.10	2.18	2.92	3.64	.29	2.79	.35	.00	.00	13.41
1883–84	.00	1.32	.00	2.76	6.33	9.68	9.77	2.60	.39	1.62	.00	.00	34.47
1884–85	.00	1.02	.79	6.62	1.23	.07	.35	3.00	.00	.00	.00	.00	13.08
1885–86	.00	.19	9.84	2.47	5.12	1.19	2.03	3.40	.00	.00	.00	.00	24.24
1886–87	.00	.39	.87	.86	.31	8.64	.13	1.43	.33	.03	.00	.00	12.99
1887–88	.38	.31	1.10	4.43	10.15	1.30	3.86	.16	.02	T.	T.	T.	21.71
1888–89	.03	.07	5.62	5.59	.29	1.29	7.31	.49	.76	.13	.00	.00	21.58
1889–90	.00	8.65	3.21	10.64	5.32	2.96	1.10	.31	.18	.00	.00	.00	32.37
1890–91	1.50	.00	.48	3.53	.50	8.82	1.65	1.90	.00	.00	.00	.00	18.38
1891–92	.18	.00	.00	2.26	1.04	2.48	3.36	.34	.62	.00	.00	.00	10.28
1892–93	.00	.42	3.70	7.31	4.52	3.55	7.53	.38	.00	.00	.00	.00	27.41
1893–94	.00	.62	T.	3.50	.65	.50	.22	.35	.86	.00	.15	.00	6.85
1894–95	1.36	.78	.11	4.16	6.25	.67	1.99	.46	.02	.05	T.	.00	15.85
1895–96	.00	.55	.77	.93	6.84	.00	2.37	1.78	.08	.05	.40	.00	13.77
1896–97	.00	.92	3.51	2.92	4.35	3.65	2.73	.02	.00	.00	.00	.00	18.10
1897–98	.00	1.44	.00	.00	.63	1.39	.28	T.	1.25	.00	T.	.00	4.99
1898–99	3.17	.14	.00	.36	4.48	.00	2.78	.64	.00	.78	.00	.00	12.35
1899–1900	.00	2.06	1.97	2.35	2.32	.05	1.58	.42	1.90	.01	.02	T.	12.68
1900–1901	.04	.15	3.99	.02	4.86	3.65	.16	2.07	.34	.10	.06	.09	15.53
1901–2	.36	2.42	1.16	T.	1.36	4.40	2.89	1.40	.07	.00	.00	.00	14.06
1902–3	.00	1.48	4.01	2.24	2.06	1.63	6.12	2.91	.00	.00	.00	.00	20.45
1903–4	T.	T.	.05	T.	.46	4.69	4.40	1.89	.09	.00	.00	.10	11.68
37-year mean													16.78

As has been previously stated, the rainfall for the drainage basin of the Santa Ynez above the Mono, and for Mono Creek, is taken in the computations as 16.78 inches as an average, which is the rainfall observed for thirty-seven years at Santa Barbara.

The drainage area above the various reservoir sites was carefully determined from the topographic surveys of the Geological Survey which have been recently made. The area above the Juncal reservoir site is 13.4 square miles; above the Mono reservoir site, 119 square miles; above the Main River reservoir site, on the Santa Ynez just below the mouth of Blue Canyon, 71 square miles; above the Gibraltar reservoir site on the main river, 207 square miles.

The exposure of the drainage basin of the Santa Ynez proper is more favorable for a large amount of run-off than that of the Mono. The rainfall usually increases as the mountains rise in elevation, but the heaviest precipitation is generally just beyond the crest of the range of hills; consequently we would expect an unusually large precipitation just beyond the summit of the Santa Ynez Range north of Santa Barbara. Moreover, this exposure being a northern one, there is less loss by evaporation from the soil. This rainfall is strikingly indicated by the brush cover on the Santa Ynez Mountains as compared with the cover in the drainage basin of the Mono.

As an illustration, it may be mentioned that during the season of 1902–3 the Mono drainage basin discharged 8,934 acre-feet of water from 119 square miles; the Santa Ynez above the Mono discharged 9,898 acre-feet from 71 square miles, and the basin above the Gibraltar dam site discharged 21,202[a] acre-feet from 207 square miles.

By applying the diagram (fig. 1) showing the relation of rainfall to run-off to the drainage areas of each of the sites, the probable volume of water available at each in each year has been obtained and is given in the last three columns of table 12. It will be noted that there is a very great fluctuation in the volume discharged in various years. For instance, in 1875–76 there were probably 35,190 acre-feet of water discharged through the Gibraltar reservoir site; in the following year there were no flood discharges whatever; while in the year 1877–78 there were probably 66,240 acre-feet. This is a strong argument in favor of building reservoirs of sufficient capacity to hold over from years of abundance to years of deficiency. It would not be possible to catch and retain all the water in all of the years, as there is a limit to the height of dam that should be built to be commercially profitable.

In consulting a table of estimated discharge of stream flow for any given section, it must be borne in mind that the figures are purely hypothetical, exact determination being impossible, for numerous reasons. The character of the run-off is dependent upon the character of each particular rain storm, whether it is a gentle shower or violent downpour. Again, one storm quickly following another will produce a greater stream discharge, because there is less opportunity of absorption of the rain by the ground. The character of the exposure, forest cover, etc., all enter into the considerations, rendering the question one of great intricacy. The table given is based upon general results obtained in southern California and must be considered merely as an estimate made from the most reliable data in hand. In order to obtain intelligent results along these lines, it is exceedingly important for the city of Santa Barbara to maintain gagings on Santa Ynez River continuously, particularly during the construction of the tunnel prior to the building of the dam at Gibraltar.

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[a] Estimated.

TABLE 12.—*Hypothetical run-off for Santa Ynez reservoir sites on basis of observed Santa Barbara rainfall and run-off diagram.*

Year.	Rainfall of Santa Barbara and Santa Ynez.	Run-off per square mile in acre-feet.	Total run-off in acre-feet.			
			Juncal (drainage area, 13 square miles).	Mono (drainage area, 119 square miles).	Main river (drainage area, 71 square miles).	Gibraltar (drainage area, 207 square miles).
1867–68	25.19	210	2,730	24,990	14,910	43,470
1868–69	15.77	60	780	7,140	4,260	12,420
1869–70	10.27					
1870–71	8.91					
1871–72	14.96	50	650	5,950	3,550	10,350
1872–73	10.50					
1873–74	14.44	40	520	4,760	2,840	8,280
1874–75	18.71	105	1,365	12,495	7,455	21,735
1875–76	23.07	170	2,210	20,230	12,070	35,190
1876–77	4.49					
1877–78	29.51	320	4,160	38,080	22,720	66,240
1878–79	13.58	40	520	4,760	2,840	8,280
1879–80	25.64	230	2,990	27,370	16,330	47,610
1880–81	15.25	50	650	5,950	3,550	10,350
1881–82	14.27	40	520	4,760	2,840	8,280
1882–83	13.41	30	390	3,570	2,130	6,210
1883–84	34.47	430	5,590	51,170	30,530	89,010
1884–85	13.08	30	390	3,570	2,130	6,210
1885–86	24.24	190	2,470	22,610	13,490	39,330
1886–87	12.99	30	390	3,570	2,130	6,210
1887–88	21.71	150	1,950	17,850	10,650	31,050
1888–89	21.58	150	1,950	17,850	10,650	31,050
1889–90	32.37	370	4,810	44,030	26,270	76,590
1890–91	18.38	90	1,170	10,710	6,390	18,630
1891–92	10.28					
1892–93	27.41	255	3,315	30,345	18,105	52,785
1893–94	6.85					
1894–95	15.83	60	780	7,140	4,260	12,420
1895–96	13.77	40	520	4,760	2,840	8,280
1896–97	18.10	90	1,170	10,710	6,390	18,630
1897–98	4.99					
1898–99	12.35	20	260	2,380	1,420	4,140
1899–1900	12.68	30	390	3,570	2,130	6,210
1900–1901	15.53	60	780	7,140	4,260	12,420
1901–2	14.06	40	520	4,760	2,840	8,280
1902–3	20.45	120	1,560	[a] 14,280	[b] 8,520	24,840
1903–4	11.68	15	195	1,785	1,065	3,105

[a] Measured flow, 8,934 acre-feet. [b] Measured flow, 9,898 acre-feet.

TABLE 13.—*Measured run-off of Santa Ynez River and Mono Creek for 1902–3.*

Month.	Total run-off in acre-feet.	
	Mono at dam site (drainage area, 119 square miles).	Main river above Mono (drainage area, 71 square miles).
1902.		
July	0	0
August	0	0
September	0	0
October	0	0
November	173	280
December	12	111
1903.		
January	676	1,193
February	389	755
March	1,845	1,230
April	4,820	4,998
May	799	1,045
June	220	286
	8,934	9,898
Estimate for 1902–3	14,280	8,520
Run-off for 1902–3, in acre-feet per square mile	75.1	139.4
1903.		
July	21	68
August	10	31
September	7	18
October	3	9
November	2	[a] 12
December	3	[a] 14
	46	152

[a] Estimated.

Run-off at Gibraltar, in acre-feet, for 1902–3.

[Estimated.]

Mono at dam site	8,934
Santa Ynez above Mono	9,898
17 square miles below Mono, estimated (17 × 139.4)	2,370
Total for Gibraltar	21,202

Total run-off, in acre-feet, of main river at Gibraltar dam site.

[Drainage area, 207 square miles.]

1903.[a]		1904.	
July	0	July	2
August	0	August	0
September	0	September	11,484
October	0	October	535
November	0	November	381
December	17	December	430
1904.		**1905.**	
January (7–31)	45	January	4,538
February	690	February	39,753
March	1,857		
April	1,125		
May	418		
June	42		
Total for season	4,194		

It is suggested that a reservoir should be so constructed as to supply at least 150 gallons per capita daily for a population of 10,000, the use and evaporation in this case amounting to about 2,100 acre-feet yearly. At the Mono reservoir site a dam 85 feet high, holding water to a maximum depth at the dam of 75 feet, would give this continuous supply for nineteen months. At the Gibraltar reservoir site a dam 100 feet high would impound a two years' supply, and a dam 155 feet high would have a capacity of 15,793 acre-feet. These figures as to flow of tne streams and capacities of reservoirs indicate the adequacy of a system based upon these physical conditions. The records of stream flow should be continuously maintained to assist in the determination of the requisite height of dam.

QUALITY OF WATER.

The quality of the water in the neighborhood of Santa Barbara has been made the subject of long study by Prof. James A. Dodge, of Santa Barbara. Herewith are given certain analyses made by him of the water of creeks in this vicinity. Although these are not absolutely complete, inasmuch as small quantities of minerals present are not stated, they were made with care. Other complete analyses that were made subsequently show no material difference from the results given. The analysis of the water of the city tunnel as supplied to consumers in Santa Barbara was made at the request of Doctor Cassal, health officer in 1899. The amount of mineral substances in solution in the tunnel water does not materially differ from that shown by the analysis made of Mission Creek waters in 1894. Other analyses made by Professor Dodge at various times, of waters from the wells

[a] Estimated.

in the city, show them to be, generally speaking, very similar to the creek water. Professor Dodge concludes that the ordinary water in use for domestic purposes from the strip of country between Santa Ynez Mountains and the ocean is practically uniform in quality. There are, however, exceptional waters in this vicinity differing decidedly from those above referred to, one of these being the Veronica water, and another the water from the Hot Springs.

ANALYSES OF SAMPLES.

Certain analyses were made of the water from Mono Creek by Prof. Laird J. Stabler, chemist for the University of Southern California and also for the Southern California Medical College, one (No. 5) being of the low summer flow, consisting of merely a few miner's inches seeping through the sands and gravels and naturally containing an abnormally large amount of mineral matter. Another (No. 7) was of the water from the first floods from the drainage basin, which, as is customary after a long drought, carried some of the accumulated salts deposited along the margins of the stream by summer evaporation, and also a large amount of pulverized sediment trampled by stock during the preceding summer and readily picked up and carried away by the first dash of water over the ground. These analyses of the low-water stage at the end of a dry season and the first flood water are the most unfavorable that could be made. The analyses of the later floods, made as the season advanced, give smaller amounts both of silt and of mineral matter, as shown in analyses No. 9 and No. 12.

Analysis No. 1, water of Mission Creek.

[Analyst, James A. Dodge; date of analysis, June, 1894.]

	Grains per U. S. gallon.
Sodium chloride	1.28
Sodium sulphate	6.95
Calcium sulphate	7.45
Calcium carbonate	6.02
Magnesium carbonate	4.21
Potassium carbonate	Trace.
Alumina and iron salts	Trace.
Silica	Trace.
Total	25.91

Reaction of residue left by evaporation in a platinum dish, slightly alkaline.

Analysis No. 2, water of Cold Spring Creek.

[Analyst, James A. Dodge; date of analysis, June, 1894.]

	Grains per U. S. gallon.
Sodium chloride	1.05
Sodium sulphate	5.96
Calcium sulphate	10.63

	Grains per U. S. gallon.
Calcium carbonate	6.25
Magnesium carbonate	6.54
Potassium carbonate	Trace.
Alumina and iron salts	Trace.
Silica	Trace.
Total	30.43

Reaction of residue left by evaporation in a platinum dish, slightly alkaline.

Analysis No. 3, water from the Santa Barbara city water tunnel.

[Analyst, James A. Dodge; analysis made in November, 1899, for Doctor Cassal, health officer.]

	Grains per U. S. gallon.
Sodium chloride	0.537
Sodium sulphate	8.392
Magnesium sulphate	3.118
Magnesium carbonate	1.769
Calcium carbonate	14.097
Iron carbonate	.122
Potassium carbonate	.379
Lithium salts	Trace.
Silica	Trace.
Nitrates	Trace.
Organic carbonaceous matter	Trace.
Total	28.414

Analysis No. 4, water from Santa Ynez River at gaging station one-half mile above mouth of Mono Creek.

[Collected by S. G. Bennett, January 4, 1903; analyst, Laird J. Stabler. Clear water; low stage before winter floods.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	2.72	4.68
Sodium sulphate	29.82	51.19
Sodium carbonate	16.57	28.41
Total solids	42.91	73.60

Analysis No. 5, water from Mono Creek at gaging station near mouth.

[Collected by S. G. Bennett, January 4, 1903; analyst, Laird J. Stabler. Clear water, low stage.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	5.94	10.20
Sodium sulphate	58.28	99.94
Sodium carbonate	17.94	30.74
Total mineral matter	81.64	140.00

Analysis No. 6, water from Santa Ynez River above mouth of Mono Creek.

[Collected by W. B. Clapp, November, 1902; analyst, Laird J. Stabler. First flood.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	2.50	3.5
Sodium sulphate	38.25	65.6
Sodium carbonate	10.13	17.38
Total solids in suspension	1,749.50	2,640.00
Total solids in solution	67.64	116.00

Solid matter deposited in 30 hours, 7.3 per cent by volume; solid matter deposited in 3 days, 7.3 per cent by volume.

Analysis No. 7, water from Mono Creek near dam site.

[Collected by W. B. Clapp, November, 1902; analyst, Laird J. Stabler. First flood.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	2.3	3.94
Sodium sulphate	33.11	56.80
Sodium carbonate	9.51	16.32
Total solids in suspension	342.80	931.00
Total solids in solution	57.15	98.00

Solid matter deposited in 30 hours, 4 per cent by volume; solid matter deposited in 3 days, 4.1 per cent by volume.

Analysis No. 7, water from Mono Creek.

[Collected January 24, 1903, at low stage; analyst, James A. Dodge.]

	Grains per gallon.
Suspended siliceous matter, separated by filtration	1.46
Sodium chloride	5.49
Sodium carbonate	3.73
Sodium sulphate	13.14
Magnesium sulphate	22.43
Calcium sulphate	10.34
Calcium carbonate	16.99
Aluminum sulphate	1.17
Iron salts	Trace.
Potassium salts	Trace.
Organic matter	Trace.
Total dissolved substances	73.29

The following analyses of waters from Mono Creek and Santa Ynez River were taken from the low stage of the stream subsequent

to the first flood, but it is believed that they still contained abnormally high quantities of solids in solution:

Analysis No. 8, water from Santa Ynez River at cable station.

[Collected by H. Rankin, January 29, 1903; analyst, Laird J. Stabler. Low stage.]

	Grains per gallon.	Parts per 100,000.
Chlorides as sodium chloride	2.04	3.5
Carbonates as sodium carbonate	14.45	24.8
Sulphates as sodium sulphate	18.49	31.72
Total solids in solution	34.99	60.00
Total solids in suspension (0.02 per cent)	11.66	20.00

Analysis No. 9, water from Mono Creek at cable station.

[Collected by H. Rankin, January 29, 1903; analyst, L. J. Stabler.]

	Grains per gallon	Parts per 100,000.
Chlorides as sodium chloride	3.67	6.3
Carbonates as sodium carbonate	10.99	18.86
Sulphates as sodium sulphate	37.00	63.44
Total solids in suspension (0.02 per cent)	13.99	24.00
Total solids in solution	56.20	97.2

Analysis No. 10, water from Santa Ynez River at cable station.

[Collected by H. Rankin, January 30, 1903; analyst, L. J. Stabler.]

	Grains per gallon.	Parts per 100,000.
Chlorides as sodium chloride	2.04	3.5
Carbonates as sodium carbonate	16.31	27.98
Sulphates as sodium sulphate	18.64	31.96
Solids in solution	44.51	69.2

Analysis No. 11, water from Mono Creek at cable station.

[Collected by H. Rankin, January 30, 1903; analyst, L. J. Stabler.]

	Grains per gallon.	Parts per 100,000.
Chlorides as sodium chloride	3.67	6.3
Carbonates as sodium carbonate	14.60	25.01
Sulphates as sodium sulphate	44.10	75.64
Solids in solution	65.42	112.0

Analysis No. 12, water from Mono Creek.

[Collected by H. Rankin, January 28, 1903; analyst, James A. Dodge. Flood water.]

	Grains per gallon.
Sodium chloride	0.99
Sodium carbonate	1.05
Sodium sulphate	7.59
Magnesium sulphate	3.52
Calcium sulphate	6.07
Calcium carbonate	7.83
Iron carbonate	.88
Potassium salts	Trace.
Organic matter	Trace.
Total	27.93

This water contained silt, suspended and subsided, consisting mainly of clay, but containing some fragments of vegetable matter, and amounting to 3½ per cent by weight of the total water. This silt subsided with moderate quickness and left the water clear in somewhat less than three days.

Analysis No. 13, water from Mono Creek.

[Collected by H. Rankin, February 26, 1903; discharge, 4.50 second-feet; analyst, L. J. Stabler.]

	Grains per gallon.	Parts per 100,000.
Sodium chloride	4.01	6.87
Sodium carbonate	2.00	3.43
Sodium sulphate	14.85	25.46
Potassium sulphate	1.02	1.72
Calcium sulphate	30.45	52.22
Calcium carbonate	3.82	6.56
Magnesium carbonate	8.42	14.43
Total	64.57	110.69

The mineral matter is rather excessive for domestic purposes. The alkali salts are not beyond the limit for irrigation, but amount present would be large for some soils. The water would form considerable hard scale in boilers. As this is a low-water sample, it shows more mineral salts than flood-water samples.

Analysis No. 14, water from Mono Creek.

[Collected by H. Rankin, February 26, 1903; discharge, 4.5 second-feet; analyst, James A. Dodge.]

	Grains per gallon.
Sodium chloride	3.97
Sodium carbonate	3.91
Sodium sulphate	13.84
Magnesium sulphate	21.55
Calcium sulphate	8.37
Calcium carbonate	22.02
Iron carbonate	Trace.
Aluminum sulphate	0.52
Potassium salts	Trace.
Silica	0.41
Total	74.59
Suspended matter	0.29

Analysis No. 15, from Santa Ynez River at Gibraltar.

[Collected by L. M. Hyde, May 2, 1904; discharge, 16.97 second-feet; analyst, James A. Dodge.]

1. General character of the water.

Clear, colorless, free from odor, of good taste; showing a slight sediment in the bottle, not sufficient for quantitative determination. Reaction slightly alkaline.

2. Organic matter.

A microscopic examination of the very small amount of matter separated by filtering, including the above-mentioned sediment, showed some plant fibers and parts of vegetable organisms; also a few infusoria in a state of activity. These are usually present in river and lake waters.

3. Chemical analysis of the mineral matter in solution.

	Parts per 100,000.	Grains per U. S. gallon.
Calcium carbonate	34.98	20.393
Calcium sulphate	4.03	2.350
Magnesium sulphate	25.78	15.030
Sodium sulphate	12.57	7.328
Sodium chloride	3.64	2.122
Potassium carbonate	1.05	0.612
Lithium salts	Trace.	Trace.
Iron salts	Trace.	Trace.
Nitrates	Trace.	Trace.
Silica	Trace.	Trace.
Total	82.05	47.835

The foregoing substances are to be understood as in the anhydrous state.

	Degrees.
Total hardness	37
Permanent hardness	20
Temporary hardness	17

The total and the permanent hardness were determined by the use of a standardized soap solution. The temporary hardness is found by subtracting the permanent from the total.

The U. S. gallon of 231 cubic inches is the basis of these results, not the imperial gallon, as formerly customary.

This analysis shows that the water is of good quality for domestic use and for irrigation. For table use, like the water of all streams in this vicinity, it would be improved by boiling and settling. This process removes a considerable part of the mineral matter and destroys infusoria and other living organisms. For use in steam boilers it would be advisable to submit this water to a softening treatment before taking it into the boilers.

DISCUSSION OF ANALYSES.

Up to January 28, 1903, this season was not productive of floods, the precipitation having been largely in the form of snow in the higher mountains, and the high water occurring later in the spring. For this reason all of the samples except Nos. 6, 7, and 12 were taken

when the stream was at low stage. The water that runs off the surface of the ground in floods will not contain as much mineral matter as that which seeps through the soil into the stream during its low stage. Samples Nos. 12 and 13 show this to be true. It is probable that over 80 per cent of the total annual discharge of the Mono will be in freshets. This being the case, we may expect the water that is stored in reservoirs to be more nearly like the flood-water than the low-water samples analyzed. If the low-water flow tends to deteriorate the whole impounded in the reservoir, it may be carried around the reservoir in a conduit.

The first flood that is flushed over the surface of a drainage basin after a drought will absorb more mineral matter than later floods will find. Thus sample No. 12 shows better water than No. 7. Sample No. 12, from the second flood water of the Mono, shows a water practically the same as that now being used by the city of Santa Barbara from Mission Creek and the city tunnel. The low-water samples contain a high per cent of mineral, but even they are pronounced harmless by Mr. Dodge. The water of the Santa Ynez above the Mono is better than the Mono water. The water stored at the Gibraltar site would be a blended water, grading between the two; and in view of the fact that this is the only source of supply open to the city for an adequate amount of water, it is believed that it should be accepted.

Prof. James A. Dodge, a chemist of marked and recognized ability, residing at Santa Barbara, who made a number of the foregoing analyses, gives the following statement about the quality of this supply:

On the supposition that the proposed reservoir on Mono Creek will be filled with the flood water of the creek, but that the water running in the creek during its low stages will also pass into the reservoir, the water as supplied to this city from that source will in its composition come between the samples analyzed by me and reported on the 16th and 21st of February [No. 12] and the 4th of March [No. 14], and might under certain conditions approximate to the first of these samples.

Considering, therefore, this low-water sample, I call attention to the fact that the principal mineral ingredients—that is, those present in greatest quantity—are the familiar calcium and magnesium salts of our hard waters. A person drinking a quart of this water would take into his stomach from 12 to 13 grains of these salts. He would at the same time take about 5 grains of sodium salts, equally common in our natural waters as used for domestic purposes, together with a very small amount of other harmless mineral substances.

In my opinion, these quantities of all these substances, taken in water, would not be sufficient to produce any deleterious or unpleasant effects upon a person in good health, properly supplied with food. Nor would the habitual use of the water bring about any bad consequences. In the case of some persons in delicate health, or of persons fasting, the same substances in the same quantity contained in the water would probably have the medicinal action of an aperient. This opinion is based on actual experience in the use of such water by myself and by others in the same company.

I will add that this water by being boiled would be caused to deposit a part of the calcium and magnesium salts, in the form of carbonates, and would thereby be improved. Furthermore, aside from the removal of a part of the mineral matter, all water taken from streams and lakes, in view of the possibility of its contamination by disease germs, needs boiling to make it perfectly safe for domestic use. After being boiled and decanted from the precipitated substances, the water, if placed in a suitable receptacle, will keep as long as may be desired and will be quite potable from first to last.

As regards the use of the Mono Creek water for cooking purposes, in my opinion the quantity of mineral substances introduced into the articles cooked with it would not be sufficient to produce any noticeable effects.

For washing this is a hard water. It would, with ordinary soaps, be somewhat more troublesome than the waters now supplied to the people of this city.

In the irrigation of trees, shrubs, and other plants, this water would not produce any injurious effects, unless applied in extraordinary quantity or on soil with little or no drainage.

It must be admitted that these waters are not of high grade for domestic use because of the large quantities of mineral matter in solution, but it is not believed that they will be injurious to health, nor will they be harmful to vegetation. The sulphate of sodium is not harmful, and the sulphate of lime tends to neutralize the carbonates. All stream waters contain more or less mineral matter. Chemically pure water is neither pleasant to drink nor healthful. The question of soils becoming alkaline from irrigation with salty water is largely dependent upon the slope and drainage that the soil itself has. In a hill country water containing unusual quantities of alkali may be used with impunity, while in a flat country a water of much better grade could not be applied in irrigation without producing bad effects. No organic impurities, which are most to be feared, will be found in these waters in dangerous quantities.

It should be stated that the samples Nos. 4 to 11, given Professor Stabler, were not large enough in volume to permit of complete analysis.

Mr. Thomas H. Means,[a] of the Bureau of Soils of the Department of Agriculture, makes the following comment upon the quality of the water as indicated by the foregoing analyses:

I have examined the analyses given in your report to the city water commissioners of Santa Barbara, Cal., with a view to determining whether these waters would be considered favorable for city use or not. I have considered the sources as free from contamination through animals and consequently have confined my attention to the mineral ingredients which the water carries.

As I understand the situation, the water which you propose to carry through the mountains by a tunnel is to be stored in a reservoir on Santa Ynez River and comes in something like equal parts from Santa Ynez River and Mono Creek. The analyses in your report are

[a] Mr. Means has since been appointed engineer of soils of the Reclamation Service.

from samples taken from both streams. The following table is a recapitulation of the analyses, showing only the total solids in 100,000 parts of water:

Comparison of analyses of Santa Ynez and Mono water.

Date.	Stage of Santa Ynez River.	Parts per 100,000.	Date.	Stage of Mono Creek.	Parts per 100,000.
1903.			1903.		
Jan. 4	Low stage before floods.	73.60	Jan. 4	Low stage before floods.	140.00
Nov.[a] —	First flood	116.00	Nov.[a] —	First flood	98.00
Jan. 29	Low stage	60.00	Jan. 29	Low stage	97.20
30	do	69.20	30	do	112.00
			28	Flood	48.30
			26	Low water	110.69
			26	do	129.00

[a] 1902.

All of these samples, with one exception, are collected at low stage of the stream, when the amount of soluble matter is usually highest, or at first flood after the dry season, when the accumulations of saline matter from the surface of the soil are swept into the stream. So these analyses probably represent the worst condition of the water. The only flood sample is that from the Mono Creek collected January 28, 1903, and its analysis shows considerably less than half the soluble matter found in the low-stage flow of the stream. I presume if flood samples were collected from the Santa Ynez a similar falling off in amount of soluble matter would be noted. The importance between this difference in low-water and flood stages is very great, especially where the floods can be stored and where it may be possible to divert the low-water flow and carry it around the reservoir.

The waters of Mono Creek seem to carry much more soluble matter than do those of the Santa Ynez. The average of the analyses given under the first four dates in the table shows Mono Creek to carry nearly 49 per cent more soluble matter than does Santa Ynez River. If the same ratio holds during the flood season the mixture of waters in the two streams should carry less than 40 parts per 100,000 parts of water, or a water, as will be shown later, which, according to the most rigid standards in eastern cities and in Europe, would be classed as "good" for domestic use. On the other hand, if the low-water discharge alone is considered the average of a mixture of the two waters would be about 114 parts per 100,000. Later I will show that according to accepted standards this amount of soluble matter is well within the limit of western American sanitary engineers.

The standard most generally accepted in eastern United States and Europe allows 50 parts per 100,000 parts of water. More than that quantity serves to condemn a water or class it as a water only "fair" for domestic use, while waters carrying less than 50 parts are classed generally as good. E. W. Hilgard, of the University of California, places the limit for domestic use at 40 grains per gallon (68.6 parts per 100,000). J. K. Haywood, chief of the water laboratory of the Bureau of Chemistry in the United States Department of Agriculture, in an article on Analysis of Waters and Interpretation of Results, published in the Department of Agriculture Yearbook for 1902, makes the following statement: "Some water analyzers would cast aside all doubt by declaring that waters containing above 686 parts per million (68.6 parts per 100,000) are to be condemned, but such is not the case, as there are many instances, especially in the West, of water containing 1,200 parts per million (120 parts per 100,000) and over being used without apparent evil results."

As a matter of precedent, I might say that there are a number of small western towns

using water carrying more than 100 parts soluble matter per 100,000 parts of water, and that the city of Phoenix, Ariz., supplies about 15,000 people with water carrying from 102 to 136 parts, without apparent inconvenience or harmful effect. Numerous domestic supplies for families have been observed by myself carrying from 400 to 500 parts per 100,000, all without evil effect and with no inconvenience except that the waters were unpalatable at first. The inhabitants of some parts of the Southwest have become so used to the saline waters that I have seen pure water salted at table to bring back the familiar taste

I find it very difficult to draw any definite conclusions from the character of the salts in the water, for I am not familiar with the methods employed by the chemists in calculating these analyses. However, it seems that the most important constituents are salts of lime. These serve to make the water hard, will cause considerable losses in soap used, and will give trouble in boiler use by forming scale. I can not say how much of this hardness is "temporary" and how much "permanent." The two analyses, Nos. 13 and 14, are evidently made from duplicate samples by two chemists working independently. One of them, No. 13, would be classed as a hard water with nearly all the hardness permanent, or, in other words, it could not be removed by boiling. On the other hand, when we consider analysis No. 14, nearly one-half of the hardness is temporary, or could be removed by simply boiling and allowing the sediment to settle. If a new set of analyses were made I would suggest they be made by some accepted standard of water analyses and both "temporary" and "permanent" hardness be determined.

Of the other salts present only the sodium sulphate and magnesium sulphate are present in sufficient quantity to warrant consideration. Both these salts are laxative, but only the most delicate constitutions would be affected by the small amounts taken in this water. Newcomers to the locality might notice the effect of the water for a few days, but I am sure no evil effects can possibly come from the constant use of such water.

The small amounts of sodium carbonate would either neutralize the effects of part of the calcium sulphate or would react with some of the magnesium salts to lower the amount of "permanent" hardness. The amount of sodium chloride is so small as to be negligible in considering the value of the water.

In summing up the matter I will say that I think the flood flow of the united Santa Ynez and Mono will prove to be well within the limits set down by the most rigid eastern standards, and that from the available analyses even the low-stage flow will be found to be well within the limits allowable for western cities and much lower in salt contents than many waters which have been in use for a long time without deleterious effects.

If further analyses are made I would suggest that both "temporary" and "permanent" hardness be determined and that some attempt be made to collect flood samples as well as the normal and low stage from both streams.

In respect to the amount of solid matter in the stream, it will be seen that there was less silt in the first flood water from the Mono than from the Santa Ynez; the reverse may be expected under ordinary conditions. Both of these analyses show the percentage of wet silt by volume at the expiration of a short period of settlement. This determination of solid matter by volume gives an exaggerated idea of the way in which the silt might be expected to destroy the storage capacity of the reservoir, for it will compact as it settles in the reservoir and as other silt is deposited upon it. In this manner it will solidify into soil occupying from one-half to one-quarter of the space indicated by its volumetric determination. Later floods have shown less than one-tenth of 1 per cent of silt.

The way to meet the silt problem in the future will be by building

the dams higher when their storage capacity is impaired. The elevation of the bed of the creek at the Mono reservoir site is 1,440 feet; the capacity to the 1,530-foot elevation is 6,509 acre-feet. If the water level is raised 10 feet, or to the 1,540-foot elevation, the capacity will be increased 2,254 acre-feet, or 34.6 per cent. If we consider that the reservoir will lose as much as 2 per cent of its capacity annually by silting, or 34 per cent in seventeen years, the original capacity could be restored by raising this dam 10 feet in height at the end of that period of time. In a similar manner the capacity of the Gibraltar reservoir may be increased about 30 per cent by raising the crest 10 feet above the 155-foot elevation.

FOREST COVER.

The true and permanent solution of this silting problem lies in the protection and development of the forest and brush cover of this reserve. A valuable brush cover is shown in Pl. III, *B*. Under existing conditions the Los Prietos Y Najalayegua grant is wedged in between the Pine Mountain and Zaca Lake Forest Reserve and the Santa Ynez Forest Reserve, along the canyon of Santa Ynez River. This private grant is not only pastured to sheep and goats, but is also subject to attacks from fires originating thereon which can not be properly restrained. Sheep have been described as the hoofed locusts of the mountains. Their small feet cut up and pulverize the soil, destroying the plants and roots that might otherwise escape them. They are a menace almost equal to that of fire to every drainage basin in southern California which they enter. Arrangements, if possible, should be made looking toward the condemnation of this property in some way and its addition to the forest reserves above referred to. The board of water commissioners of Santa Barbara very wisely and properly have urged this matter with the Departments at Washington, and the forestry experts who have examined the region have favorably reported upon the action suggested.[a]

With a natural increase of vegetation and protection from the fires which have raged through this district for years past it is believed that the silt danger would be largely mitigated. This is a subject which should be followed up as one of vital importance, and but one solution should be permitted, to wit, the expulsion of the sheep from the drainage basin of the Santa Ynez and the protection of the forest and brush cover from fire. Otherwise the drainage basin is satisfactory. There are practically no human habitations within its borders above the proposed reservoir sites, and probably will be none in the near future, as the country is too mountainous and too inhospi-

[a] In December, 1903, after the above had been written, an Executive order included this grant in the forest reserve, an exchange of holdings having been arranged with the owner, and now the entire reservation, including the whole basin of the upper Santa Ynez, is known as the Santa Barbara Forest Reserve.

table to admit of agricultural pursuits. The greater portion of the basin is now included in forest reserves.

RESERVOIR SITES.

JUNCAL SITE.

Mr. George Wright made surveys of the Juncal reservoir site and determined the following capacities:

TABLE 14.—*Capacities of the Juncal reservoir site for various heights of dam.*

Height of dam in feet.	Million gallons.	Acre-feet.
50	350	1,074
75	705	2,164
100	1,050	3,222
125	1,437	4,410
150	1,877	5,760
175	2,352	7,218
200	4,000	12,276

It will be noted that with a dam 100 feet high the capacity of the Juncal reservoir is 3,222 acre-feet; with a 100-foot dam on the Mono reservoir site the capacity is 8,763 acre-feet. The Mono site, therefore, has 2.72 times the capacity of the Juncal, with the same height of dam. The Gibraltar dam, 100 feet high above stream bed, will hold 6,480 acre-feet. It is believed that the Juncal reservoir site alone will not furnish an adequate water supply to the city, but when used in connection with other reservoir sites having greater drainage areas above them it may be of value. The drainage area above the Juncal is but 13.4 square miles, not 23½ square miles as reported upon previously by other engineers. The length of a dam 200 feet high at the Juncal would be 550 feet on top, and a 100-foot dam would be 272 feet.

Mr. Purslow estimated that the cost of building a 100-foot dam and a riveted-steel pipe line (which latter must be considered as temporary construction) to Santa Barbara would be $282,450. He also states that the run-off from the drainage basin of the Juncal was measured in the winter of 1895–96 and that it amounted to 2,455 acre-feet. On the other hand, it is estimated in this report (see p. 53) that the run-off of the Juncal in 1895–96 was only 520 acre-feet from 13 square miles—a figure, therefore, apparently overconservative. However, there probably was a flood in January, 1896, as the rainfall for that month was 6.84 inches at Santa Barbara and probably 9 inches in the drainage basin of the Juncal. This may have produced a rather abnormal flood condition. As Mr. Purslow gives no details of his

work, not even the length of time of his observations, his results can not be accepted as conclusive.

Mr. Wright states that the rock at this dam site, which is quite similar to the formation prevailing throughout this region, weighs 149 pounds per cubic foot. In this estimate this rock has been considered as weighing 150 pounds per cubic foot, as determined at various points along the Coast Range by geologists. Masonry work made therefrom is taken to weigh 143 pounds per cubic foot.

MAIN RIVER SITE.

The Main River reservoir site was investigated by Mr. Purslow. This also was surveyed by W. B. Clapp for the Geological Survey. We find that a dam 65 feet in height would have a storage capacity of 1,311,000 gallons, or 4,023 acre-feet, to the 65-foot flow line. Figs.

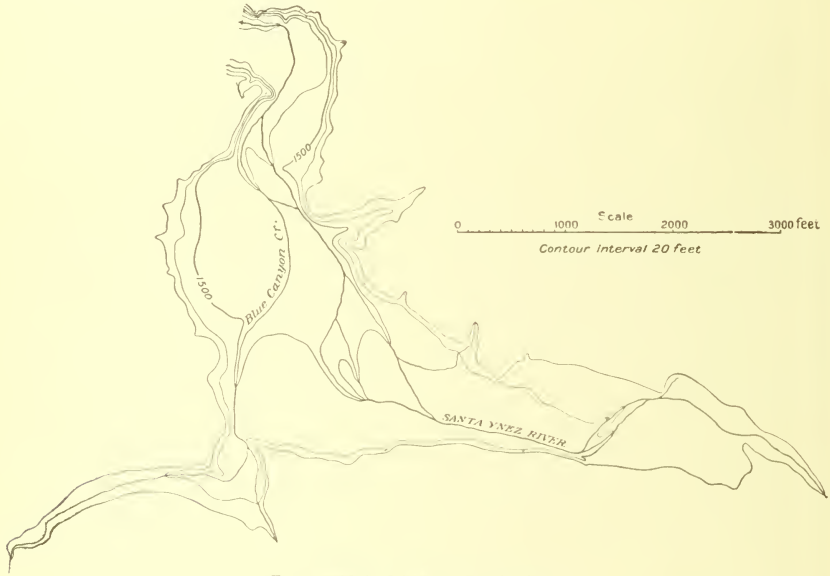


FIG. 2.—Main River reservoir site.

2 and 3 show the reservoir and dam sites. The Mono reservoir site with water held to the 75-foot level would have a capacity of 3,968 acre-feet. The Main River dam, however, would contain very much more masonry and be more expensive than the Gibraltar or the Mono dam. A dam 75 feet high at the Main River site would be 592 feet long on top and 427 feet long on the base. At the Mono dam site a dam 75 feet high would be 277.5 feet long on top and 150 feet long at the bottom. The Gibraltar is still more favorable. With an 85-foot rock-fill dam at the Mono the cost per acre-foot of capacity is $36, while at the Main River site with a 65-foot concrete dam the cost is about $154 per acre-foot of capacity, depending on depth of bed rock.

Mr. Purslow states that it would require a tunnel 15,500 feet long to pass through the Santa Ynez Range to the coast side and that the estimated cost of developing this work would be $557,000. It is believed that a shorter location can be found. The width of canyon covered by débris at the Main River dam site is so great and the depth to bed rock so uncertain that it is impossible to give even an approximate estimate of the cost of this dam. It must be of masonry, as it will have to be an overflow weir. If bed rock is taken as 25 feet below the bed of the creek, it may cost $620,000 for the dam alone.

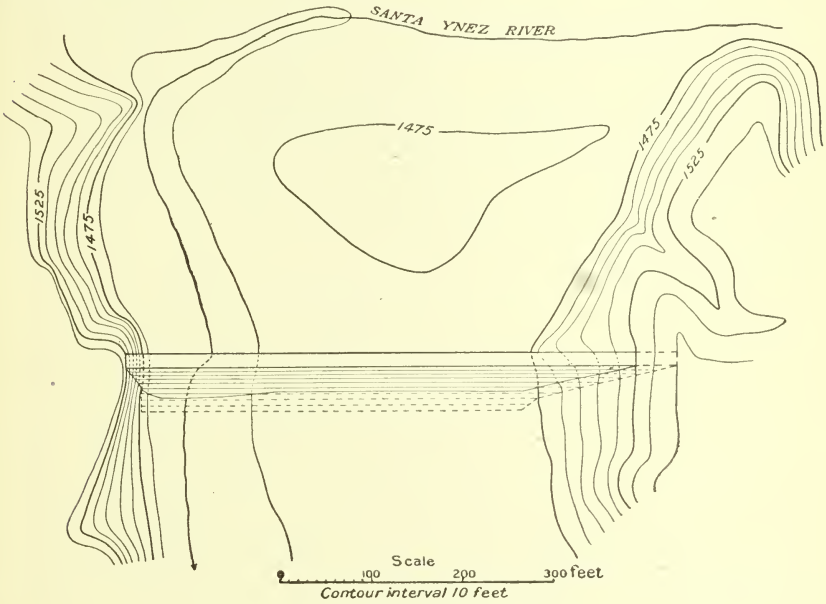


FIG. 3.—Main River dam site.

The effort has not been made in this report to go into the details of these estimates of cost for the Main River and Juncal reservoir sites. The reservoir sites are owned by the Santa Barbara City Water Company. It is believed, however, that if the city of Santa Barbara constructs a tunnel through the Coast Range, in order to lead the water from the lower reservoir sites to the city, the construction by some one of the Juncal or Main River reservoir sites may ultimately follow. This tunnel is a very large element in the cost of the work, and will require by far the greater length of time to construct. It must be so located as to permit the water from all the sites to be led through it by gravity to the coast, and its capacity must be sufficient to accommodate all of the water.

TABLE 15.—*Area and contents of Main River reservoir.*

[Survey by W. B. Clapp.]

Contour.	Acres.	Acre-feet between contours.	Total acre-feet to contour.	Capacity in millions of gallons.
1,460	0.33	.....	.....	.....
1,470	2.68	15.05	15.05	5
1,480	14.38	85.30	100.35	33
1,490	30.45	224.15	324.50	106
1,500	71.59	510.20	834.70	272
1,510	120.19	958.90	1,793.60	581
1,520	154.69	1,374.40	3,168.00	1,032
1,530	187.66	1,711.75	4,879.75	1,590
1,540	222.06	2,048.60	6,928.35	2,357
.....	.....	6,928.35	.....	

75-foot flow-line capacity=5,904.05 acre-feet.
Depth of bed rock unknown.

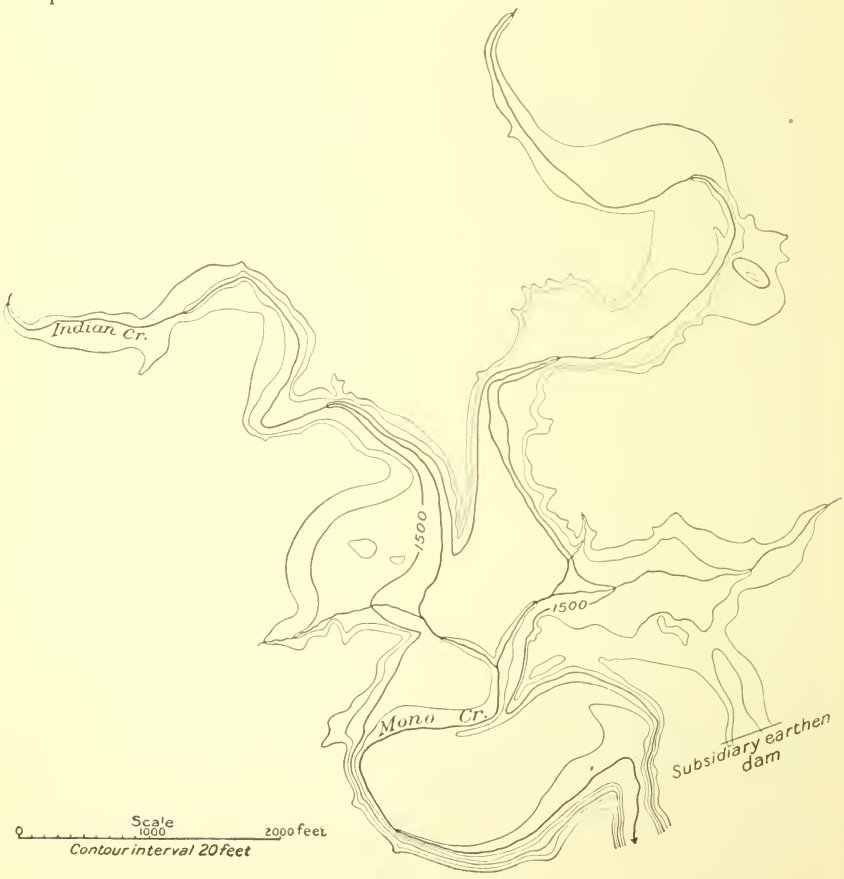


FIG. 4.—Mono reservoir site.

BLUE CANYON SITE.

The Blue Canyon reservoir site is situated in what is known as Blue Canyon, which discharges into the Santa Ynez a short distance above the Main River reservoir site. It is a good reservoir site, but as the drainage basin is only 8 square miles it is not considered feasible to fill it from its tributary natural-water supply. The Blue Canyon reservoir site is between Santa Ynez River and the crest of Santa Ynez Mountains. The length of tunnel from this reservoir site to the coast side would be 10,500 feet. To fill it from Santa Ynez River, in addition to building this long tunnel, would be too expensive a proposition to justify the construction.

MONO SITE.

A detailed and careful survey was made of the Mono reservoir and dam site by Mr. W. B. Clapp, of the hydrographic branch of the Geological Survey. Fig. 4 shows the results of these surveys, and Pl. IV, *B*, is a view of the site. The following table gives the capacity:

TABLE 16.—*Area and contents of the Mono reservoir site.*

[Survey by W. B. Clapp.]

Contour.	Area in acres.	Capacity in acre-feet between contours.	Total capacity in acre-feet.	Capacity in millions of gallons.
1,440.0	0	.....	.....	.....
1,450.0	1.2			
1,460.0	10.6	.....	[a] 94.0	.....
		59.0	.....	.....
1,461.2	.....	209.0	00.0	.....
1,470.0	31.2	.....	174.0	57
1,480.0	49.9	406.0	580.0	189
1,490.0	71.3	606.0	1,186.0	386
1,500.0	98.1	847.0	2,033.0	662
1,510.0	125.4	1,117.5	3,150.5	1,026
1,520.0	164.0	1,447.0	4,597.5	1,498
1,530.0	199.5	1,817.5	6,415.0	2,090
1,540.0	251.4	2,254.5	8,669.5	2,825

[a] Below outlet.

Total capacity in acre-feet	8,763.5
Capacity below outlet	94.0
Capacity, above outlet	8,669.5
Elevation of creek bed	1,440.0
Elevation of outlet	1,461.2

Depth of bed rock unknown.

This reservoir site has tributary to it a drainage area of 119 square miles. The creek passes first through a large flat and then through a narrow gorge. It is an unusually good reservoir site for southern California, but the dam site is poor. If the tunnel which the city is now running is continued at a grade of one-tenth of a foot rise to 100 feet horizontal, the elevation of the north portal of the tunnel on the datum plane that has been used will be 1,457.2 feet.[a] We may assume that a conduit leading from the reservoir site to the portal of the tunnel would descend approximately 4 feet in grade, giving an approximate elevation of the outlet from the reservoir as 1,461.2 feet, or 21.2 above the bed of the stream at the reservoir site. This is not of material consequence, as it is usually the case with reservoir sites that the first 20 or 30 feet above the bed of the stream at the dam site has very limited storage capacity. Thus the total storage capacity to the 100-foot flow line at the Mono reservoir site is 8,763.5 acre-feet and the capacity below the outlet is but 94 acre-feet, so that the net capacity above this outlet with a 100-foot dam would be 8,669.5 acre-feet, or 99 per cent of the total.

DISCHARGE.

Measurements of the flow of the Mono during the winter of 1902–3 were made daily, and the discharge for the season was found to be as follows:

TABLE 17.—*Estimated monthly discharge of Mono Creek at the dam site for season of 1902–3.*

[From daily measurements.]

1902.	Acre-feet.	1903.	Acre-feet.
July	0	January	676
August	0	February	389
September	0	March	1,845
October	0	April	4,820
November	173	May	799
December	12	June	220
		Season	8,934

The mean rainfall at Santa Barbara is 16.78 inches; for the last season it was 20.45 inches. Although the precipitation was in excess of the mean, the rainfall was not delivered in such manner as to produce large stream discharge and in the opinion of local residents the streams were below normal. The five preceding years were all below the mean in precipitation, so that a larger portion of the water than usual was absorbed by the ground. These measure-

[a] For more detailed statement, see p. 40.

ments of the streams should be continued so that the height of dam may be intelligently proportioned to the probable water supply. (See table 12, p. 53, showing estimated volumes of flow annually.)

CONTENTS AND COST OF DAMS.

Two types of dam for the Mono site have been considered. The rock on the sides of the canyon at this dam site is sandstone and shale, the stratification being practically vertical and the strike at right angles to the direction of the stream flow. Pl. IV, *A*, shows the character of this rock at the left abutment, which is the best. It weighs approximately 150 pounds to the cubic foot, and could be quarried in sizes and forms suitable for the work on the dam. The abutments are much better at the Mono dam site than at the Main River dam site, but not so good as at the Gibraltar. Spillway opportunities occur at the right abutment for the accommodation of flood discharges when the reservoir may happen to be full. The dam is considered in each instance to be 10 feet above the elevation of its spillway, so as to prevent the water overtopping the structure. The depth to bed rock is not known. The most serious item in connection with the construction of the dam is probably the transportation of supplies and materials to the site. In case the dam should be a cement, masonry, or concrete structure there would be a large amount of cement, which is a heavy material, to be hauled to the reservoir site. The masonry dam is believed to be the better form of construction, but because of considerations of economy the cost of the rock-fill type of dam has been computed.

These supplies for a rock-fill dam would probably be hauled by teams up Santa Ynez River from the end of the railroad at Ballard, a distance of 40 miles, or possibly through the tunnel when it is completed. The wagon road would be poor for the last 10 miles, but the grades easy. In the original estimate for this dam made for the city of Santa Barbara all material was considered as hauled by wagon to the dam site for both forms of structure. Since then (January 1, 1903) the manufacture of native cements has reduced the price of this constituent materially.

The rock-fill may be the better type for this point because of its greater economy. As the volume of material that would have to be brought in for construction purposes would be relatively small as compared with a masonry dam, it probably would not be advisable to provide for transportation through the tunnel for it, as would be necessary if a masonry dam were built. The estimates are therefore made upon this assumption. Fig. 5 shows a plan for a 110-foot rock-fill dam and fig. 6 a plan for a subsidiary earthen dam.

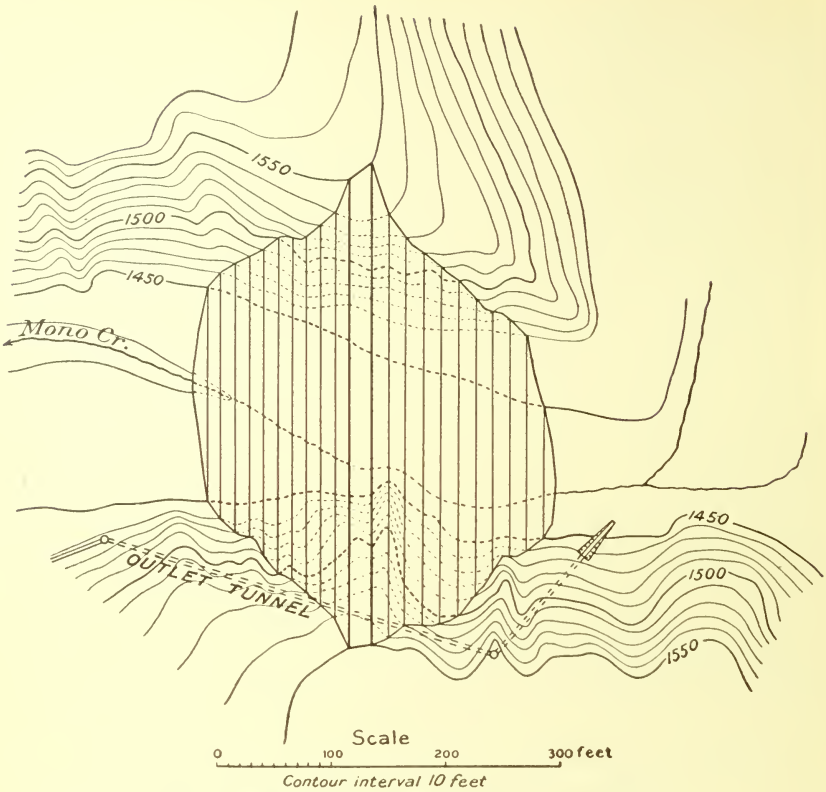


FIG. 5.—Mono dam site, showing 110-foot loose-rock dam.

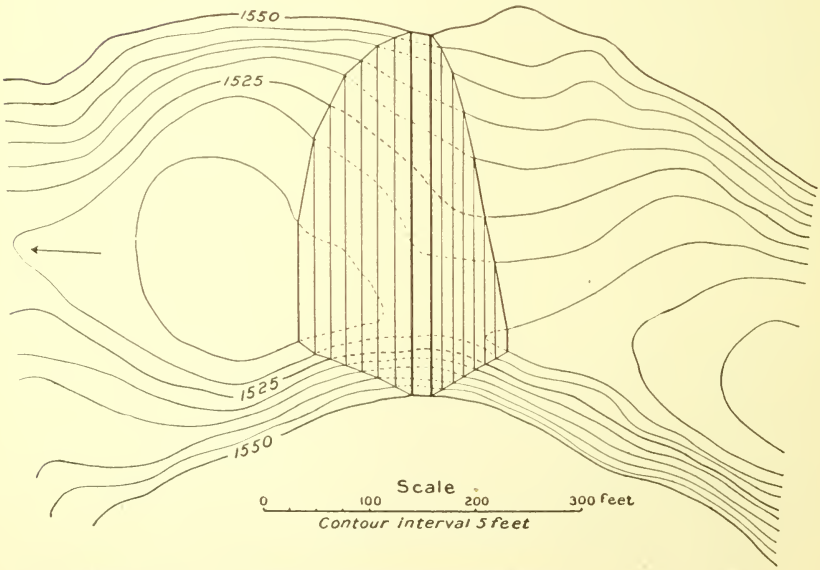


FIG. 6.—Mono dam site, showing plan of subsidiary earth dam for 110-foot loose-rock-fill dam.

All engineers connected with these investigations have declared that it is quite necessary, before preparing an accurate report and estimate on the reservoir sites, to know the position of bed rock at the place where the structure is to rest, and have recommended that these explorations should be carried out in connection with this present investigation. It has been found impossible, however, at this writing, to supply the funds to make this examination, and consequently the estimate must be taken with latitude in this regard.

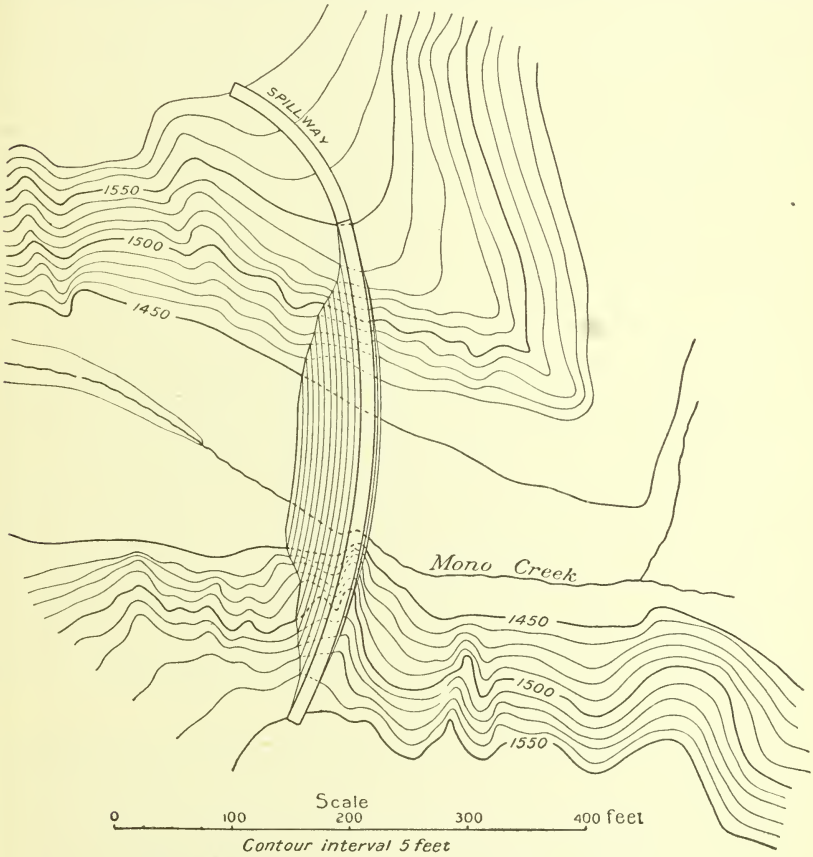


FIG. 7.—Mono dam site, showing plan for 110-foot concrete dam.

In the case of the rock-fill dam, it could rest properly and safely upon the present bowlder-covered bed of the canyon, but it would be necessary to carry down to bed rock on the upper slope an apron wall to cut off the underflow beneath the dam. This wall would be connected with a portion of the apron of the dam above ground in order to make it completely tight. It should be 8 feet thick at its base and 4 feet thick on top at the ground surface, so that for a loose-rock dam there would not be a great quantity of material to

be removed from the bed rock, and the amount of cement used would be small

In the case of a concrete or masonry dam, however, the whole structure would have to go down to the bed-rock foundation, which would have to be exposed and thoroughly cleaned. In estimating on the concrete dam it has been assumed that bed rock for the entire width of the canyon is 20 feet beneath the surface of the ground. At a point some 200 or 300 feet below the dam site a ledge of material projecting well out into the canyon, over which the stream flows, has the appearance of being bed rock or ledge matter in place. It is not known, however, whether it extends completely across the stream.

An 85-foot rock-fill dam at the Mono reservoir site would contain 75,480 cubic yards of loose rock, which, it is considered, could be quarried from cliffs that are favorably situated for $1 per cubic yard. Each yard, so thrown into the fill, would make 1¾ yards of fill; consequently a figure of 60 cents per cubic yard has been accepted. A dry-laid wall 2 feet in thickness on the upper face of the dam is provided for, upon which the asphalt-concrete apron will be laid. The upper toe wall is carried down to bed rock in the bed of the stream, 4 feet thick on top, 8 feet at base, and 20 feet high. On the sides of the dam this wall is also estimated upon to seal the asphalt-concrete to the abutments. The asphalted concrete will be put on 1½ feet thick, of broken stone, gravel, sand, and asphalt, the latter being brought from quarries on the lower Santa Ynez. The section of this dam will be 20 feet wide on top, with a very flat slope of 1½ feet horizontal to 1 foot vertical on the upper face and 1¼ feet to 1 foot on the lower face. This flat slope is given to the upper face so that there will be no movement in the asphalt apron. The asphalt also would be rammed into the crevices of the dry-laid wall on which it rests.

The spillway provisions are of vital importance in a rock-fill dam. The maximum flood that was ever measured on Sweetwater River since the dam was constructed there, some fifteen years ago, was 98 cubic feet per second for each square mile of the drainage basin. A flood discharge of Piru Creek was measured at Henderson's ranch on December 18, 1894, of 43 cubic feet per second per square mile of drainage area. On Arroyo Seco, a tributary of the Salinas in Monterey County, on November 21, 1900, a flood of 140 second-feet per square mile was observed. The rainfall, however, in the drainage basin of Arroyo Seco is exceedingly heavy. For the purposes of this report we have assumed a flood of 130 second-feet per square mile of drainage area, or a total flood discharge of 15,470 second-feet, filling the spillway to within 3 feet of the top of the dam. Before the spillway would be filled to the top of the dam the flood would have reached

26,420 cubic feet per second, or 222 second-feet per square mile of drainage basin. The spillway would be 251 feet long and the bottom of it would be 10 feet below the crest of the dam. It would be excavated from the rock at the right abutment of the dam.

A 20-inch pipe has been estimated upon, leading from the Mono reservoir site to the intake of the long tunnel through Santa Ynez Range of mountains. The aggregate cost of reservoir and pipe line to long tunnel is $140,700, or $36 per acre-foot of capacity.

In estimating upon the length of tunnel line through the Coast Range to this reservoir site we have accepted the present tunnel site and assumed that the tunnel is to be completed on an angle line, or in such manner as to avoid the property of all owners other than the city of Santa Barbara. On this basis there would still be 15,006 linear feet of tunnel to run, at an estimated cost of $12 per linear foot.

Estimate for 85-foot rock-fill dam at Mono reservoir site.

[Capacity 3,880 acre-feet.]

DAM.

75,480 cubic yards of loose rock, at 60 cents per yard	$45,288	
2,500 cubic yards of dry-laid wall (upper face), at $1 (extra)	2,500	
Upper toe and side wall to bed rock	16,500	
Asphalt-concrete face 1½ feet thick, 1,861.2 cubic yards, at $8	14,890	
Outlet tunnel, gates, and tower	10,000	
Spillway	20,000	
Clearing reservoir	2,460	
20-inch pipe line to long tunnel 7,000 feet from reservoir, capacity 189 inches	10,710	
Engineering, 5 per cent	6,117	
Contingencies, 10 per cent	12,235	
Total ($36 per acre-foot)		$140,700

TUNNEL.

15,006 linear feet of tunnel through Santa Ynez Range, via angle line, at $12 per foot	$180,072	
Road up Santa Ynez River	5,000	
Engineering, 5 per cent	9,254	
Contingencies, 10 per cent	18,507	
Total		212,833
Grand total		353,533

An estimate is also presented of the cost of building a rock-fill dam at the Mono to an elevation of 110 feet above the bed of the stream, impounding the water to the 100-foot flow line. The conditions would be the same for the construction of this dam as in the case of the 85-foot dam, except that a second small earthen dam would have to be built to close another opening; this is referred

to as the subsidiary dam. With the rock-fill type of dam it would be quite feasible to increase the height, raising the dam to such new elevation as might be desired.

Estimate for a 110-foot rock-fill dam at Mono reservoir site.

[Capacity 8,670 acre-feet, 290 miner's inches constant flow.]

142,535 cubic yards of loose rock, at 60 cents per yard	$85,521	
3,733 cubic yards of dry-laid wall, at $1 (extra)	3,733	
Upper toe and side walls	18,099	
Asphalt-concrete face 1½ feet thick, 2,772 cubic yards, at $8	22,176	
Outlet tunnel, gates, and tower	10,000	
Spillway	20,000	
Clearing reservoir, 257 acres, at $15	3,855	
Pipe line to long tunnel, 7,000 linear feet, capacity 366 inches	12,880	
25,745 cubic yards earth in subsidiary dam	7,724	
Engineering, 5 per cent	9,199	
Contingencies, 10 per cent	18,399	
Total ($24.40 per acre-foot)		$211,586
Tunnel through Santa Ynez Mountains, as above		212,833
Grand total		424,419

An estimate is also given for a masonry dam 85 feet high at the Mono reservoir site. This dam would be 12 feet wide on top, with a slope of 2 to 1 on the lower side and 20 to 1 on the upper side. The masonry would be made of hydraulic cement, which would be hauled through the finished tunnel. The outlet, tower, spillway provisions, and clearing reservoir would be the same as in the case of the rock-fill dam. The total cost of a dam of this class, including the 20-inch pipe line to the long tunnel, would be $361,690, or $93 per acre-foot of storage capacity. It thus will be seen that the masonry dam 85 feet high would cost 2.6 times what the loose-rock dam would cost. This is because the latter would be built of material at hand.

Estimate for 85-foot masonry dam at the Mono reservoir site.

[Capacity, 3,880 acre-feet.]

6,612 cubic yards masonry below surface of ground, at $15 (includes excavation)	$99,180	
22,955 cubic yards masonry above ground	172,163	
Total for dam proper		$271,343
Outlet tunnel, gates, and tower		10,000
Spillway		20,000
Clearing reservoir		2,460
7,000 feet of 20-inch conduit, capacity 189 inches		10,710
Engineering, 5 per cent		15,726
Contingencies, 10 per cent		31,451
Total		361,690

Cost per acre-foot of capacity, $93

QUICKSILVER MINE DAM SITE, RIGHT ABUTMENT.

QUICKSILVER MINE RESERVOIR SITE.

View upstream from dam site.

QUICKSILVER MINE SITE.

A site called the Quicksilver mine reservoir site was discovered about 4 miles below the mouth of the Mono. At this point the river

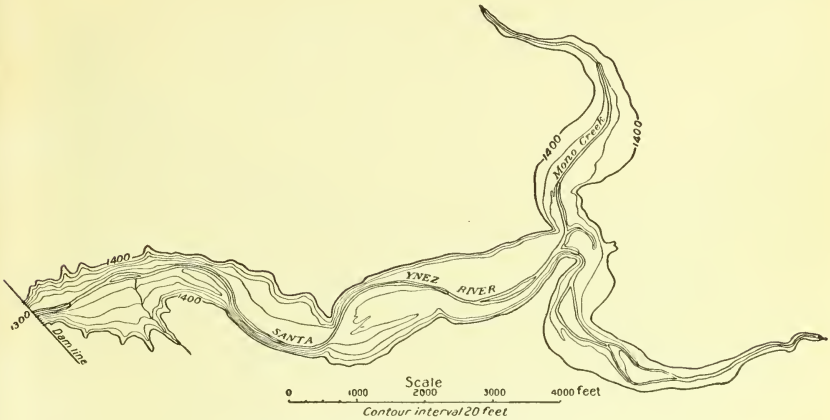


FIG. 8.—Quicksilver mine reservoir site.

passes through a rather narrow canyon of shale rock, shown in Pl. VI. The site itself is shown in Pl. VII. The capacity of this reservoir is

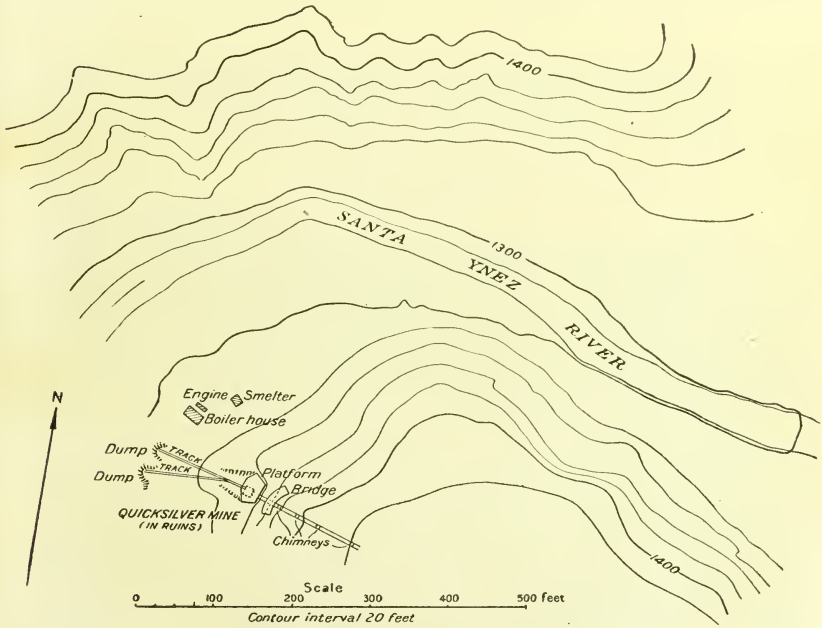


FIG. 9.—Quicksilver mine dam site.

large, but the dam site is not satisfactory because of the absence of suitable building material, and also on account of the character of the abutments. Figs. 8 and 9 show the reservoir and dam sites.

Water impounded to a depth of 100 feet in this reservoir would be flooded back a short distance into the Mono and up the Santa Ynez above the mouth of the Mono. The following is a table of the capacity of this reservoir.

TABLE 18.—*Capacity of Quicksilver mine reservoir site.*

Contour.	Area in acres.	Average area in acres.	Capacity in acre-feet.	
			Between contours.	Total to contours.
1,300	0.57	3.70	37.0	37.0
1,310	6.83	12.05	120.5	157.5
1,320	17.28	26.15	261.5	419.0
1,330	35.01	45.66	456.6	875.6
1,340	56.31	74.02	740.2	1,615.8
1,350	91.73	112.07	1,120.7	2,736.5
1,360	132.42	143.55	1,435.5	4,172.0
1,370	154.69	172.71	1,727.1	5,899.1
1,380	190.74	212.15	2,121.5	8,020.6
1,390	233.56	255.69	2,556.9	10,577.5
1,400	277.82	.....	.....	.....

The Quicksilver mine reservoir site, while of satisfactory capacity, is not considered a feasible proposition because of the character of the dam site.

GIBRALTAR SITE.

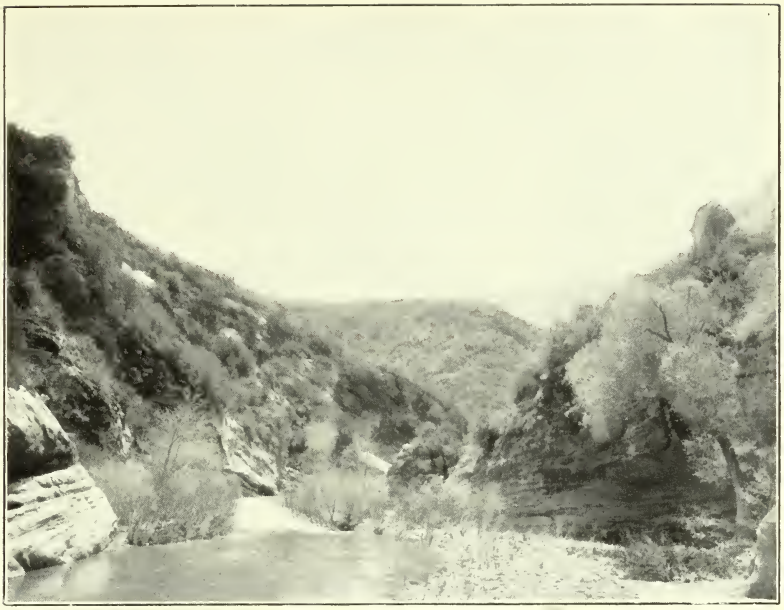
DISCHARGE.

The Gibraltar reservoir site is situated 6 miles below the mouth of Mono Creek on Santa Ynez River. The drainage area tributary to it includes all of the Mono, the main river above the Mono, and 17 square miles additional. The discharge as estimated from the rainfall for the seasons from 1867–68 to 1903–4, inclusive, is shown in table 12 (see p. 53), and as measured[a] for 1902–3 in table 13 (see p. 54). From these it appears that the discharge is from 1.8 to 2.4 times as great as that of the Mono.

CONTENTS AND COST OF DAMS.

The reservoir site, which is shown in fig. 10, lies along a narrow, canyon-like valley with a light grade. The dam site is a rather peculiar and unusual one. An anticlinal fold of sandstone, apparently uplifted through the shales, has been cut by the river in a narrow gorge, as shown in Pl. VIII, *A* and *B*. The crest of this fold is almost level and

[a] Partly estimated.



A. GIBRALTAR DAM SITE, LOWER END OF GORGE.

View upstream.

B. GIBRALTAR DAM SITE, UPPER END OF GORGE AT PROPOSED AXIS OF DAM.

View downstream. Stream turns abruptly to the left. The spillway site is over the crest on the left.

is approximately 150 feet above the bed of the stream, so that a dam built slightly higher than the crest, or, say, 155 feet, will have the advantage of a natural spillway of great length on the side away from the dam and over solid rock. This is the only dam site that has been found in the upper portions of Santa Ynez River where the abutments are of a satisfactory nature and where the building material could be gotten out in such sizes and shapes as may be desirable for the construction of any type of dam.

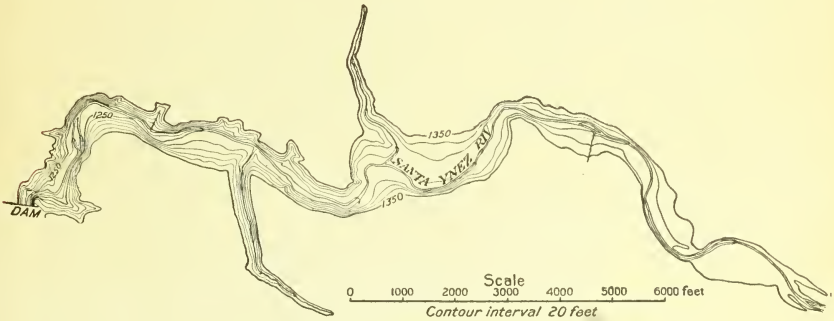


FIG. 10.—Gibraltar reservoir site.

A determination of the specific gravity of this rock has been made by weighing the rock first in air and then in water, which gave a specific gravity of 2.56. Four tests were made, ranging from 2.55 to 2.57. This is equivalent to a weight of 160 pounds per cubic foot. In rubble masonry, one-third of the bulk being mortar and two-thirds solid rock, and the mortar being considered as weighing 103 pounds, the weight would be 140 pounds per cubic foot of masonry in dam.

The ledges are in such a position as to permit a most economical handling of material for masonry construction.

TABLE 18a.—*Capacity of Gibraltar reservoir site.*

[Elevation of surface of stream bed, 1,215 feet.]

Contour.	Area in acres.	Average area in acres.	Capacity in acre-feet.	
			Between contours.	Total to contours.
1,215	0	----------	----------	----------
1,220	2.12	----------	----------	----------
1,230	5.74	3.93	39.3	39.3
1,240	13.26	9.50	95.0	134.3
1,250	22.67	17.97	179.7	314.0
1,260	32.37	27.52	275.2	589.2
1,270	50.11	41.24	412.4	1,001.6
1,280	66.24	58.17	581.7	1,583.3
1,290	90.06	78.15	781.5	2,364.8
1,300	119.62	104.84	1,048.4	3,413.2
1,310	152.74	136.18	1,361.8	4,775.0
1,320	188.33	170.53	1,705.3	6,480.3
1,330	227.13	207.73	2,077.3	8,557.6
1,340	271.39	249.26	2,492.6	11,050.2
1,345	296.64	284.01	1,420.0	12,470.2
1,350	332.75	314.70	1,573,5	14 043.7
1,355	367.07	349.91	1,749.6	15,793.3

Table 19 shows the volumes of material for a rock-fill dam situated at the Gibraltar reservoir site, the upper slope to be 1½ to 1, the lower slope 1¼ to 1, the width on top 20 feet, and the height of dam 155 feet, or 10 feet above the level of the spillway. The top of the crest is taken to be at the 1,360-foot contour. Bed-rock conditions are unknown, but for the purpose of this estimate are assumed to be at 1,205 feet. Repeated efforts were made to provide for an exploration of bed rock at this dam site, but owing to financial condi ions and negotiations for the purchase of the property by the city of Santa Barbara it was not possible to arrange for this. The capacity with this dam to the 1,350-foot contour in the reservoir would be 14,044 acre-feet. Fig. 11 shows the plan for a 155-foot rock-fill dam.

In the table 7,444 cubic yards are deducted from the total estimated volume in the dam, as the rock fill will go down only to the 1,210-foot contour, except where the toe walls are located, where they are assumed to go as low as the 1,205-foot contour. The excavation of the spillway is taken at 1,250 cubic yards, which of course would be used in the construction of the dam. The spillway could probably

be made much wider, if desired, in excavating the material for the dam. In this estimate it is taken as 350 feet in width.

A dam of this type is considered as having 12,083 cubic yards in asphalt-concrete face and dry-laid wall, this face to be put on as indicated in the drawing and to be covered by the dry-laid wall, to

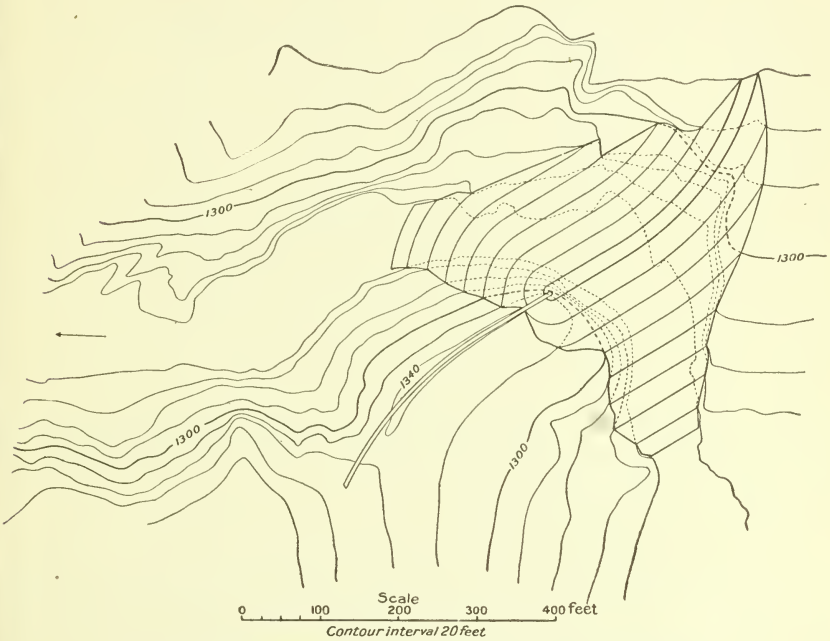


FIG. 11.—Gibraltar dam site, showing plan for 155-foot rock-fill dam.

protect it from the sun, so as to prevent the movement of the asphalt. If this volume is deducted from the total yardage given in the dam, in addition to the deduction mentioned above on account of the rock-fill dam not going down to bed rock for its entire length, the net volume of rock fill will be 233,724 cubic yards.

TABLE 19.—*Volume in rock-fill dam at Gibraltar dam site.*[a]

[Capacity to 1,350-foot contour, 14,044 acre-feet.]

Contour.	Volume between contours in cubic yards.	Contour.	Volume between contours in cubic yards.
[b] 1,205	.....	1,320	15,231
1,210	7,444	1,330	13,194
1,220	14,713	1,340	10,916
1,230	16,648	1,350	8,148
1,240	19,805	1,360	4,796
1,250	21,536	Total	253,251
1,260	22,185	Deduct [c]	7,444
1,270	21,860		245,807
1,280	20,925	Deduct [d]	12,083
1,290	19,981	Net	233,724
1,300	18,768		
1,310	17,101		

[a] Contents of spillway masonry dam—1,250 cubic yards. Spillway dam, 5 feet wide on top; 0.05 to 1 slope on upstream face; 10 feet down, 7 feet thick; 15 feet down, 9 feet thick; 20 feet down, 13 feet thick. Spillway is 350 feet in width; in excavating for dam it may be made wider, the limit in width being the limit of excavations.
[b] Bed rock as estimated, but not determined.
[c] Rock fill goes only to 1,210-foot contour.
[d] Asphalt face and dry-laid wall.

The hand-laid facing on top of the asphalt-concrete is estimated to be 3½ feet thick and the asphalt-concrete 1½ feet, covered with an impervious layer of asphalt two-tenths of a foot thick. The concrete cut-off wall at the upper toe of the dam is estimated as 90 feet long, with a height above assumed bed rock of 5 feet and a thickness on top of 5 feet, downstream vertical, upstream with a slope of 1 to 5 and a thickness at base of 6 feet.

The outlet system would consist of a tower reaching from the 1,220-foot contour to the 1,360-foot contour, a height of 140 feet. The internal diameter of the tower would be 8 feet at top and the thickness of wall 2 feet at top and 6 feet at bottom, the tower standing on a solid concrete base 5 feet thick and 21 feet in diameter. Following is an estimate of the cost:

Estimate of cost of 155-foot rock-fill dam at original site of Gibraltar dam.

Rock fill, 233,724 cubic yards, at 60 cents	$140,234.00
Hand-laid facing, 8,458 cubic yards, at $1.60	13,533.00
Asphalt and concrete facing, 3,625 cubic yards, at $8	29,000.00
Cut-off wall	1,493.00
Overflow weir and subsidiary dam, 1,250 cubic yards, at $9	11,250.00
Clearing reservoir site, 333 acres, at $25	8,325.00

Outlet system:		
Tower, 911 cubic yards, at $9.30	$8,472.00	
Inlet pipes	460.00	
Valve rods	860.00	
Outlet valves	1,000.00	
Outlet tunnel, 1,000 feet, at $5	5,000.00	
Tower house and bridge	500.00	
Total of outlet system		$16,292.00
		220,127.00
Contingencies, 10 per cent		22,012.70
Engineering, 5 per cent		11.006.35
Total		253,146.05

The rock-fill dam can be built only to such height as will permit complete spillway opportunities around the end of the dam. It is, however, feasible to build a masonry dam that will not be the full height, permitting the water to waste over the top of the dam during different stages of its construction. For instance, the dam could be built to a height of 50 or 100 feet, and construction stopped until the demands or desires of the city should call for its completion; the final structure could then be built to its ultimate height of approximately 155 feet. When the dam was completed to its full height the overflow and waste water could then be directed through the spillways.

If such a dam should be built of cyclopean rubble masonry on a gravity section and also on a curve, the top would stand at the 1,360-foot contour. The estimate given below is based on bed rock being at a depth of 5 feet beneath the present stream bed, but it is not known what the depth actually is, and the final estimates might be greatly modified by these conditions. A determination of this point is essential before beginning the construction of the dam and before the final estimate on its cost can be made.

Three estimates have been prepared on the assumption that the dam will not be built to its full height from the start. These are for dams 95 feet high, with a capacity of 3,413 acre-feet, equivalent to a continuous flow of 4.715 second-feet, or 236 miner's inches per annum; 125 feet high, with a capacity of 8,558 acre-feet, equivalent to a continuous flow of 11.82 second-feet, or 591 miner's inches per annum; and 155 feet high, with a capacity of 15,793 acre-feet, equivalent to a continuous flow of 21.81 second-feet, or 1,090 miner's inches per annum.

These estimates of discharge are on the assumption that the reservoir would be filled by the stream every year. This, however, can not be done, for in some winters there will be little more addition to the reservoir than enough to make up for evaporation. If it is assumed that the 155-foot dam is built, and that its capacity is

15,793 acre-feet, and that this will have to furnish the supply of water for nineteen months, the yield will be 831 acre-feet monthly; with the reservoir half full the monthly loss by evaporation would average about 66 acre-feet, leaving 765 acre-feet monthly for distribution during the dry period, or a continuous flow of 13 second-feet, equivalent to 650 miner's inches, or 8,400,000 gallons daily. Putting it another way, the flow will be approximately 900 miner's inches in the summer time and 400 miner's inches in the winter time. Fig. 12 shows a plan of a 155-foot masonry dam.

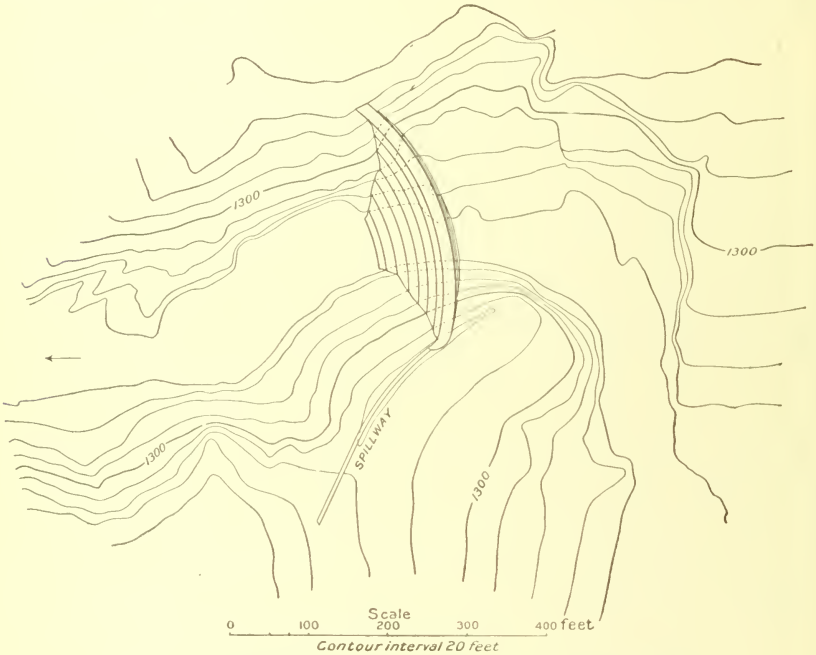


FIG. 12.—Gibraltar dam site, showing plan for 155-foot masonry dam.

With the lower size dam the surplus water is considered as wasted over the top of the dam, and the dam is made safe on the gravity section with 10 feet of water passing over its crest; in addition it is to be a curved dam. These same conditions will obtain with a dam 125 feet high. The 155-foot masonry dam is designed to let the surplus water pass through a spillway, the water standing within 5 feet of the top of the dam, and the capacity being 15,793 acre-feet. This is a greater capacity than that for the 155-foot rock-fill dam, because with the rock-fill dam greater safety in spillway capacity would be required, and this type would have to be built at least 10 feet above the level of the spillway. Figs. 13, 14, and 15 give sections of the dams considered. In the estimates masonry weighing 140 pounds per cubic foot is used.

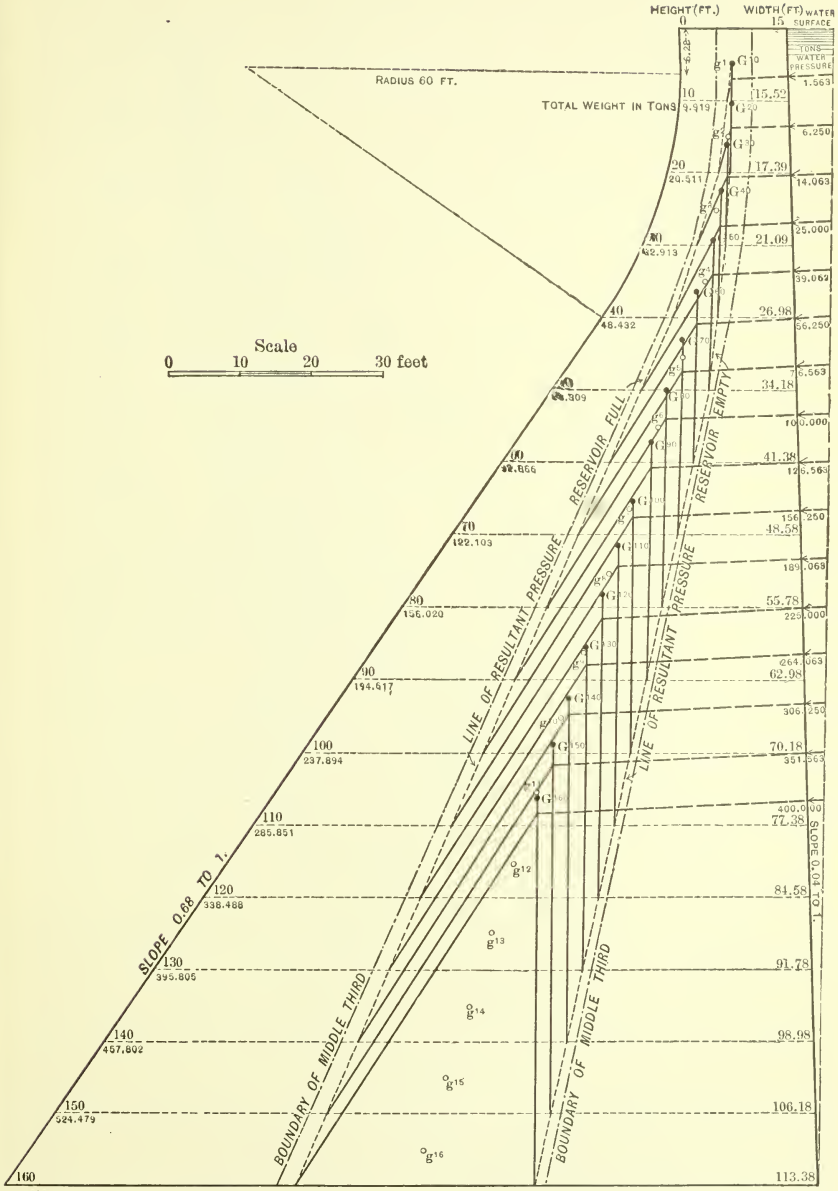


FIG. 13.—Section of masonry dam for Gibraltar reservoir based on concrete weighing 130 pounds per cubic foot.

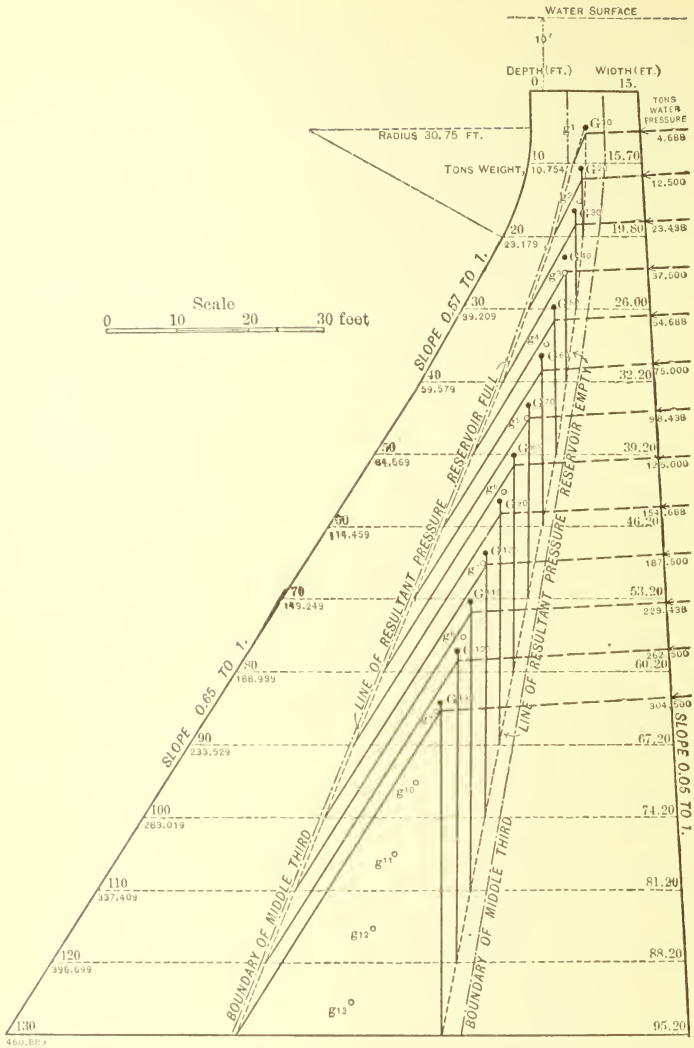


FIG. 14.—Section of masonry overflow weir dam based on masonry weighing 140 pounds per cubic foot.

The following is an estimate on three types of dams:

Estimate of cost of 95-foot masonry overflow dam located at lower site of Gibraltar dam.

[Capacity 3,413 acre-feet.]

Masonry, 15,331 cubic yards, at $7	$107,317.00
Excavation to bed rock, 1,280 cubic yards, at $2.50	3,200.00
Clearing reservoir, 120 acres, at $25	3,000.00
Outlet system, tower, gates, tunnel, etc	9,971.00
	123,488.00
Contingencies, 10 per cent	12,348.80
Engineering, 5 per cent	6,174.40
Total	142,011.20

Cost per acre-foot of capacity, $41.61.

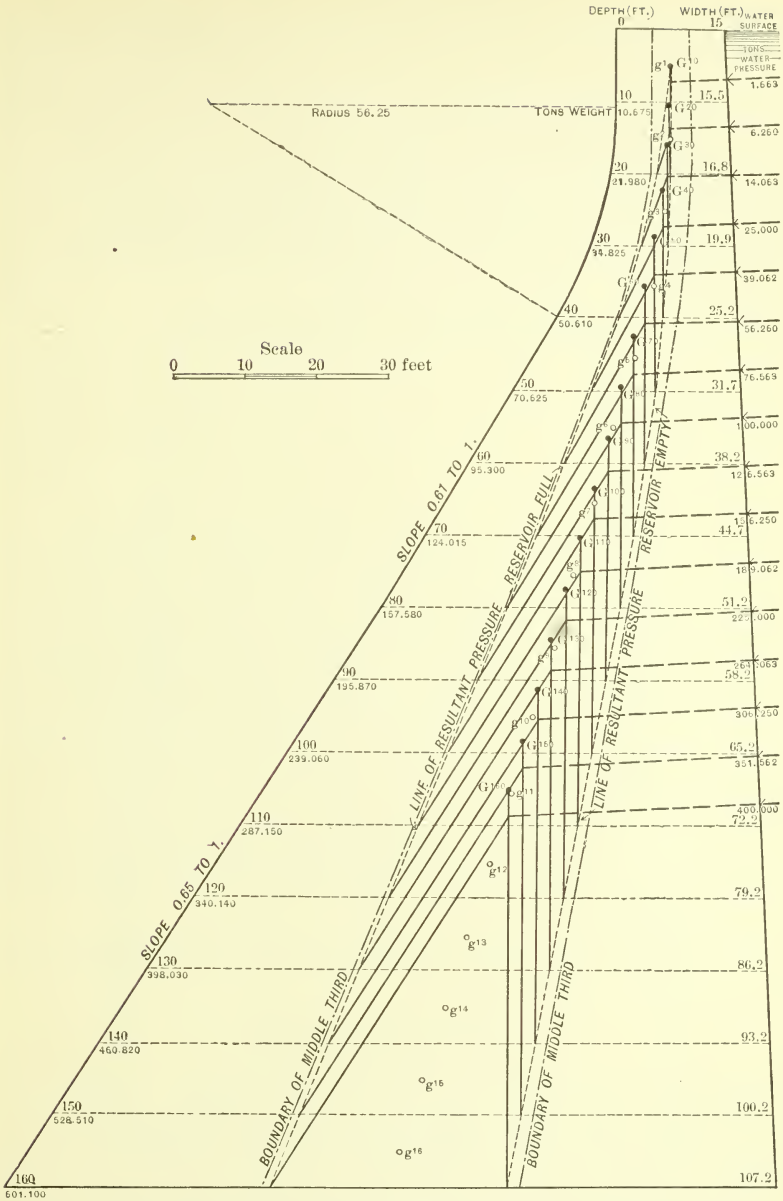


FIG. 15.—Section of masonry dam based on masonry weighing 140 pounds per cubic foot.

Estimate of cost of 125-foot masonry overflow dam located at lower site of Gibraltar dam.

[Capacity 8,558 acre-feet.]

Masonry, 27,971 cubic yards, at $7	$195,797.00
Excavation to bed rock, 1,579 cubic yards, at $2.50	3,948.00
Clearing reservoir, 227 acres, at $25	5,675.00
Outlet system, tunnel, gates, tower, etc	13,000.00
	218,420.00

Contingencies, 10 per cent	$21,842.00
Engineering, 5 per cent	10,921.00
Total	251,183.00

Cost per acre-foot of capacity, $29.35.

Estimate of cost of 155-foot masonry dam located at lower site of Gibraltar dam.

Masonry in dam, 42,250 cubic yards; masonry in spillway, 833 cubic yards; masonry in protection wall, 56 cubic yards; total masonry, 43,139 cubic yards, at $7	$301,973.00
Excavation to bed rock, 1,731 cubic yards, at $2.50	4,328.00
Clearing reservoir, 350 acres, at $25	8,750.00
Outlet system, tower, gates, tunnel, etc	16,292.00
	331,343.00
Contingencies, 10 per cent	33,134.30
Engineering, 5 per cent	16,567.15
Total	381,044.45

The flood discharge from these drainage basins is considered in the discussions of the spillway for the Mono reservoir site. Taking a maximum flood discharge of 130 cubic feet per second per square mile from the entire 207 square miles that are tributary to the Gibraltar reservoir site, the spillway of 600 feet in length would be running full and the water passing 3½ feet deep over the top of the masonry dam. This would be a most extraordinary flood, and it is believed that the dam, with the gravity section that it has, in addition to its arched shape, would stand this.

In the case of the 125-foot dam such a flood would pass over the crest of the dam 9½ feet deep, and the dam is designed to withstand with safety an overflow of 10 feet on a gravity section without the aid of its curved shape.

For the 95-foot dam under similar conditions the depth of water would be 11 feet.

TUNNELS TO GIBRALTAR SITE.

Because of its elevation and location it will not be possible to use the old city tunnel in Cold Spring Canyon in reaching the Gibraltar reservoir site. The elevation of the surface of the water at the Gibraltar, with a dam 155 feet high, is 1,360 feet above sea level, and the estimated elevation of the northern end of the old Cold Spring Canyon tunnel at its northern portal would be 1,457 feet. The location also is not suitable for the Gibraltar site. Because of these facts, a new tunnel location was sought as an outlet for the Gibraltar reservoir site. The triangulation was extended so as to cover the distance intervening between Mission Canyon and the Gibraltar dam site, and it was found that a tunnel from Mission Canyon to the Gibraltar would be 19,560 feet in length, and from Rattlesnake Canyon to the

Gibraltar it would be 20,763 feet in length. The length necessary to complete the old tunnel from Cold Spring Canyon through to Santa Ynez is 14,901 feet. It must be remembered, however, that the old tunnel has very irregular grades, that the cross section of it is not uniform, and that the alignment is irregular. In addition to that, the present heading is 5,000 feet from the portal, so that the total length of the Cold Spring Canyon tunnel, if completed, would be 19,901 feet. Because of these irregularities in the old tunnel and the dis-

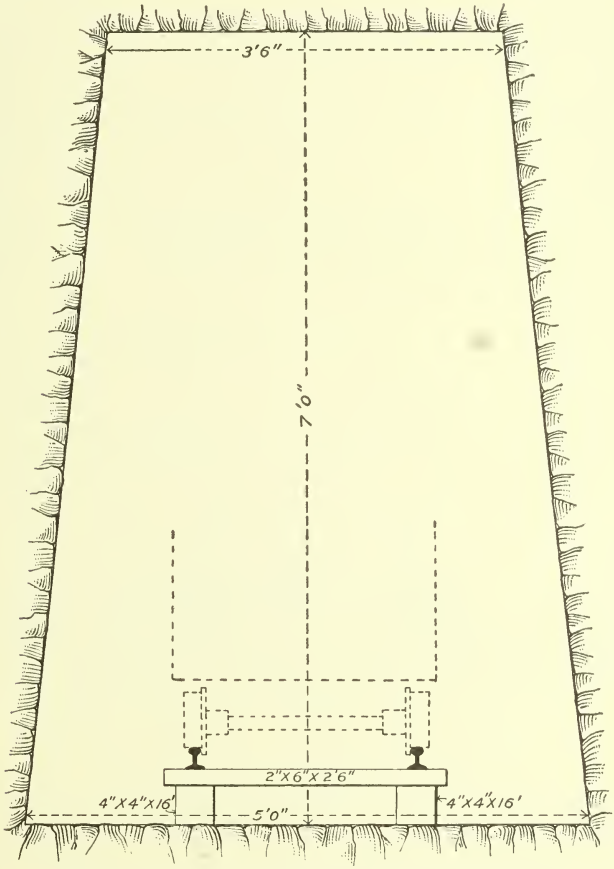


FIG. 16.—Section of new Santa Barbara tunnel in solid rock.

tance in from the heading, it has been estimated that the cost to complete it would be at the rate of $12 a foot; the total cost of completing it, building roads, engineering, etc., having been previously estimated at $212,833 (see p. 77).

The following is an estimate of the cost of building the Mission or the Rattlesnake tunnel.[a]

[a] Since writing the above, contracts have been entered into for the construction of the Mission Canyon tunnel line at a figure slightly below this estimate (see p. 43). Figs. 16 and 17 show sections of this tunnel.

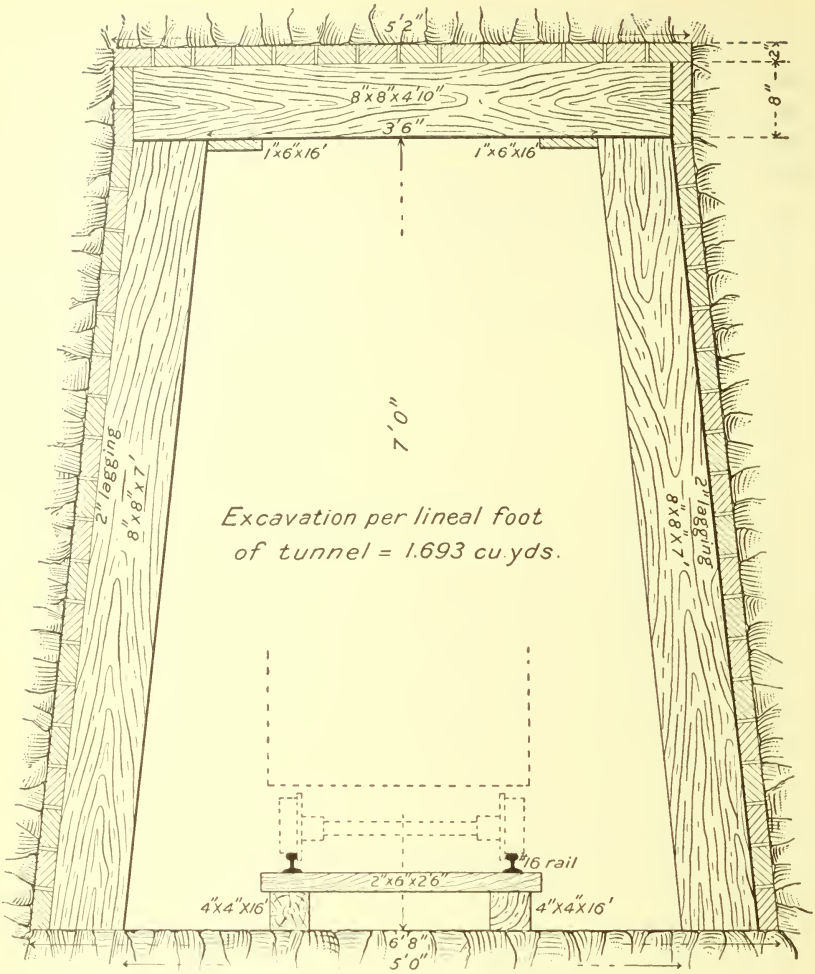


FIG. 17.—Section of new Santa Barbara tunnel in loose rock.

Estimate of cost of building Mission Canyon tunnel.

[Length based on triangulation by L. M. Hyde.]

19,560 linear feet, at $10 per linear foot	$195,600
Road up Santa Ynez River	2,500
Road up Mission Canyon	2,500
Engineering, 5 per cent	10,030
Contingencies, 10 per cent	20,060
Total estimated cost	230,690

Estimate of cost of building Rattlesnake Canyon tunnel.

[Length based on triangulation by L. M. Hyde.]

20,763 linear feet, at $10 per linear foot	$207,630
Road up Santa Ynez River	2,500

Road up Rattlesnake Canyon	$3,500
Engineering, 5 per cent	10,682
Contingencies, 10 per cent	21,363
Total estimated cost	245,675

COMPARISON OF GIBRALTAR AND MONO SITES.

In order to compare the costs of the combined tunnel and reservoir for the Gibraltar site and for the Mono site, the following table is given:

TABLE 20.—*Comparative estimates of dams and tunnel lines at Gibraltar and Mono.*

GIBRALTAR.	
95-foot masonry overflow dam (3,413 acre-feet, at $41.61)	$142,012
19,560 feet of tunnel (Mission line)	230,690
Total	372,702
125-foot masonry overflow dam (8,558 acre-feet, at $29.35)	251,183
19,560 feet of tunnel (Mission line)	230,690
Total	481,873
155-foot masonry dam (15,793 acre-feet, at $24.13)	381,044
19,560 feet of tunnel (Mission line)	230,690
Total	611,734
155-foot rock-fill dam (15,793 acre-feet, at $16.02)	253,146
19,560 feet of tunnel (Mission line)	230,690
Total	483,836
MONO.	
85-foot rock-fill dam (3,880 acre-feet, at $36)	140,700
15,006 feet of tunnel	212,833
Total	353,533
110-foot rock-fill dam (8,670 acre-feet, at $24.40)	211,586
15,006 feet of tunnel	212,833
Total	424,419
85-foot masonry dam (3,880 acre-feet, at $93.22)	361,690
15,006 feet of tunnel	212,833
Total	574,520

The masonry dam is the better form of construction for a storage reservoir. In addition the abutments at the Gibraltar reservoir site are much more secure and satisfactory than at the Mono site. The water supply is more than twice as great at the Gibraltar as at the Mono and its quality is better.

Making the comparison for masonry dams, it will be seen that the cost for the 155-foot masonry dam at the Gibraltar site would be

$24.13 per acre-foot of water impounded, while for the 85-foot masonry dam at the Mono site it would be $93.22 per acre-foot.

With a 125-foot masonry dam at the Gibraltar, the capacity of the reservoir would be 8,558 acre-feet, and the total estimated cost of the dam and tunnel would be $481,873.

A 110-foot rock-fill dam at the Mono would have a capacity of 8,676 acre-feet, and with the completion of the Cold Spring tunnel would cost $424,419, which is less than the cost of the Gibraltar 125-foot dam. The Gibraltar dam, however, would undoubtedly be safer, have fully twice the water supply available for dry years, and would furnish better water. These things considered, there can be no doubt whatever that it is advisable to construct the Gibraltar dam with the Mission Canyon tunnel, rather than the Mono site with the completion of the Cold Spring Canyon tunnel.

The real governing factor in the entire situation is the quantity and quality of the water, and on this basis there can not be any doubt that the Gibraltar site is far the better. During the winter of 1902–3 the total discharge of Mono Creek at the Mono reservoir site was 8,934 acre-feet, while at the Gibraltar it was 21,202 acre-feet, or 2.4 times as much. In addition the situation is such at the Gibraltar site that the masonry dam can be gradually built higher as the demand of the city for a greater water supply grows, while there are distinct limitations to the construction of a higher dam at the Mono site.

FINANCIAL STATEMENT.

The financial results to be expected from the expenditure of the money necessary to build the work above referred to are not extensively considered, because it is not so much a question of whether these works can be constructed at a commercial profit as it is a question of how much it will cost to get an adequate water supply for the locality. It goes without saying that if the coast district is to continue to grow it must have water, and the only question is whether this can be obtained at reasonable cost.

The output from this system should be 1½ million gallons daily for 10,000 people. On page 25 it is shown that in order to meet the worst-known drought of nineteen months and deliver 150 gallons daily for 10,000 persons, plus the evaporation, a storage capacity of 3,518 acre-feet is required. This is on the assumption that all of the water must come from the reservoir and none can be obtained from the tunnels or streams on the south side of the range, a condition which the writer believes never will exist, but which he assumes for safety. At the Gibraltar site a dam 95 feet high will practically accomplish this at a cost for dam and tunnel of $372,702. Assuming an interest rate of 4½ per cent on this cost, we shall have an annual

fixed charge of $16,772. The works will all be permanent. Construction and maintenance charges should be very low, say $4,000 per annum. Operation should not be over $2,000. This gives a total annual charge of $22,772 for 547 million gallons, or a maximum of 4.1 cents per 1,000 gallons delivered at the intake of the domestic system. As the dam is increased in height the cost per unit of storage and the proportional charge for the tunnel will rapidly decrease with the resulting increased supply. With a dam 155 feet high on the above basis the cost per thousand gallons would be 1.1 cents. The long tunnel will undoubtedly also itself contribute a material supply to the city. Mr. Canfield, the president of the Santa Barbara Water Company, states as follows:

Water is now sold in Santa Barbara at the rate of about 16 cents per thousand gallons to the city for street-sprinkling purposes (at the rate of $35,000 per year for 1 second-foot), and to private consumers at from 20 cents to 25 cents per thousand gallons, which are moderate rates as compared with those realized in some other cities in this State, and it is believed that although the development of the business in the future may justify some reduction of rates, an average rate of 15 cents per thousand gallons at least can be calculated upon.

This is certainly a very reasonable charge for water in southern California. The lowest meter rate known in the State (that of the city of Los Angeles) is 9 cents per 1,000 gallons delivered to the consumer. Of course, there must be an intermediate charge for distribution system and administration which comes after the water is delivered to the mains.

Both Mr. Wright and Mr. Purslow considered the construction of these storage reservoirs as a profitable investment from a commercial standpoint. If the water was delivered free at sea level to the city, it would cost two-thirds as much for fuel alone (say 2.7 cents), with triple-expansion engines, to pump it to the city reservoir as it would to obtain it from this contemplated system of storage reservoirs. If interest, depreciation, and services are considered it would cost more to pump it.

There would undoubtedly also be a very considerable element of profit that might be derived from the water power available from the supply, since the elevation of the southern portal of the tunnel is approximately 1,200 feet and the elevation of the domestic reservoirs only 350 feet.

The result of the construction of the long tunnel probably will be the construction of the dam to the maximum height commensurate with the water supply of Santa Ynez River by the city, or by other parties who might make arrangements with the city for carrying water through this long tunnel. This should be a condition that the city would encourage.[a] The water not required by the

[a] Since writing the above the city has entered into a contract with the Santa Barbara Water Company to permit of such a use of the city tunnel by the company.

municipality would be used in developing and irrigating the beautiful coast plain near Montecito or in other adjoining localities. The improvement of this region would, of course, add to the prosperity of the county and city of Santa Barbara.

In this report estimates on right of way have not been included.

CONCLUSIONS.

In conclusion it may be stated—

(1) That the only extensive addition that can be made to the water supply of the Santa Barbara coastal plain is by the construction of a tunnel from Santa Ynez River to the coast side of the mountains and the building of an impounding reservoir for the holding of the winter flood waters of Santa Ynez River.

(2) That by far the most desirable point on Santa Ynez River for this construction is the Gibraltar reservoir site.

(3) That the water can be delivered at a reasonable cost for both irrigation and domestic use to Santa Barbara and vicinity from this site, and the construction is believed to be entirely justified and commercially feasible.

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

THE LIGNITE OF NORTH DAKOTA

AND ITS RELATION TO IRRIGATION

BY

F. A. WILDER

WASHINGTON

GOVERNMENT PRINTING OFFICE

1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
HYDROGRAPHIC BRANCH,
Washington, D. C., June 18, 1904.

SIR: I have the honor to transmit herewith a report by Prof. F. A. Wilder on the lignite of North Dakota and its relation to irrigation, and recommend that it be published in the series of Water-Supply and Irrigation Papers.

The investigation on which this report was based was carried on under the charge of Mr. N. H. Darton as a part of the general investigation of the underground-water resources of the western portion of the United States. It is thought that the information contained in the paper will be of interest in connection with the underground-water resources of North Dakota.

Very respectfully, F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

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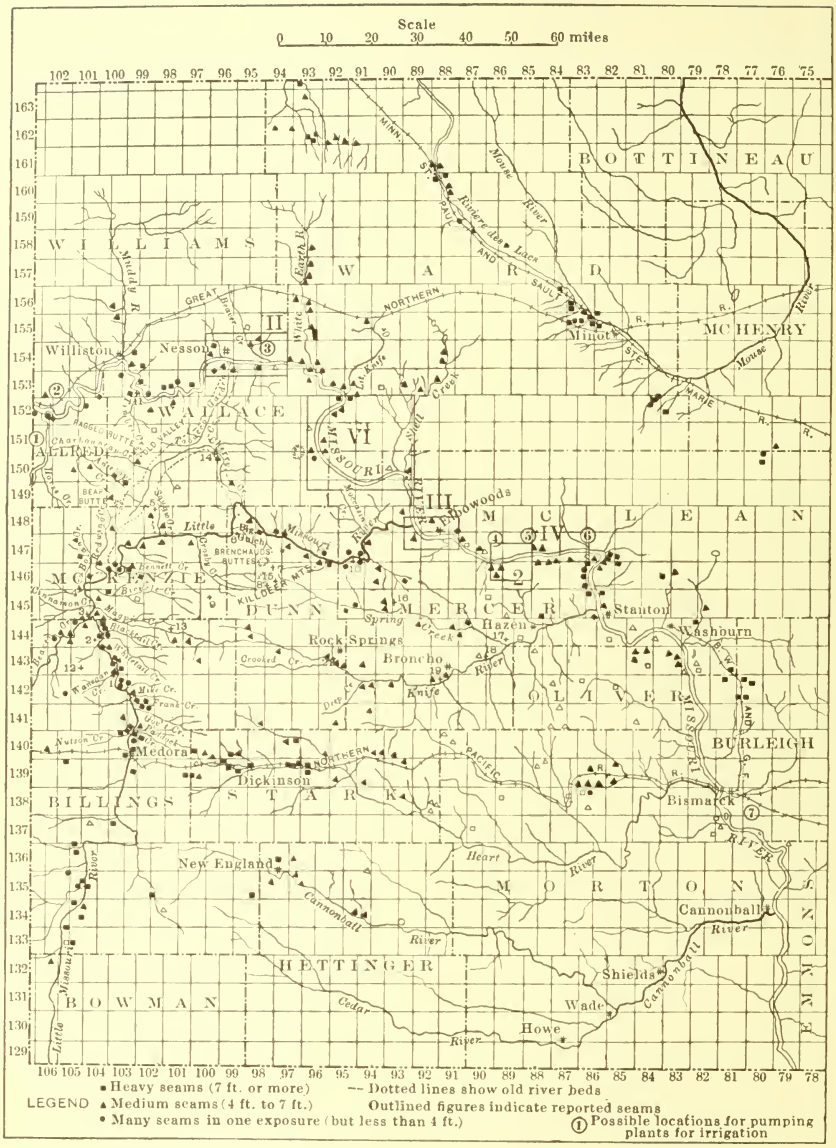
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THE LIGNITE OF NORTH DAKOTA AND ITS RELATION TO IRRIGATION.

By F. A. Wilder.

INTRODUCTION.

The areas most favorably situated for irrigation in North Dakota are the broad terraces along the Missouri and its tributaries. These streams are deeply intrenched, and it does not seem possible by means now available to raise water from them a vertical distance of from 150 to 400 feet over the bluffs that rather sharply bound the broad valleys.

When the Yellowstone enters the State it has a fall per mile of only 2.7 feet, while the Missouri's gradient for an equal distance is about 2 feet. A fall of 1 foot per mile is necessary to carry water in an irrigating ditch, so that to raise water 40 feet above the Missouri would require a ditch 40 miles long. The tributaries of the Missouri have gradients somewhat higher, but the flats along them are cut up by the meandering of the streams, and conditions are not favorable for long lateral ditches or extensive reservoirs.

On account of the fertile terraces in the valleys of the streams, ranging from 15 to 100 feet in elevation above water level, and the abundance of lignite along them, it seemed desirable to consider the possibility of irrigating the 250,000 acres included in the stream terraces by pumping from the rivers directly, using lignite as fuel. The lignite area, therefore, has been studied, and the nature of the lignite beds investigated. Practical tests have been made to determine the value of this material as fuel for generating steam, and computations have been made to ascertain, at least in a rough way, the cost of irrigating river flats which are less than 100 feet above the streams. The Missouri and its tributaries in North Dakota have been followed, and the extent and elevation of the river flats and the amount and quality of the lignite near them have been noted.

If only a small fraction of the western part of the State is under irrigation, the productiveness of the whole region will be greatly increased. Every river valley contains land which may be considered with reference to irrigation possibilities. With a few acres which can be watered at will, and abundant range for cattle in the broken

or rolling land back of the valley, ten families, by combining farming with cattle raising, will prosper where one finds a living now. These conditions will lay a sure foundation for the dairying industry, which should be one of the foremost of the State.

LIGNITE AREA IN NORTH DAKOTA.

While thin beds of lignite have been recognized in the eastern part of the State and have been previously described,[a] the only workable beds east of the center of the State are in the Turtle Mountains and at the southern bend of the Sheyenne River, about 25 miles southeast of Valley City, the Turtle Mountains being an outlier of the lignite area proper. The region in which lignite may reasonably be expected to be found, and which is discussed in this bulletin, may be roughly bounded on the east by a line beginning at the northern boundary of the State, 30 miles east of the Minneapolis, St. Paul and Sault Ste. Marie Railway, and extending southeast to Harvey, thence south through Steele to the southern boundary. More careful study, aided by well borings, which will doubtless be made as the country is settled, will perhaps shift this line at certain points 30 or 40 miles east or west. On the north, south, and west the lignite continues beyond the boundaries of the State. This region is of very great extent, having an area equal to half of that of the State of Ohio.

It is highly probable that lignite does not exist in beds of workable thickness in every part of this region, but it is equally probable that the fraction of the area lacking lignite in beds of three or more feet in thickness is a small one, not more than one-fifth of the whole. In the southeastern portion of the area, about the lower part of Cannonball River, thick beds seem to be lacking. Where heavy beds are present, all may not be available, either on account of depth or some difficulty in mining, and throughout the eastern portion of the region they are so thoroughly concealed by glacial drift that without a knowledge of the underlying formations and of the surrounding country their existence would be unsuspected.

The restriction of the term lignite area to the region in which workable beds of lignite are found greatly simplifies the stratigraphic series and limits this section to a consideration of the Laramie and the glacial drift.

The Laramie, which is the latest stage of the Cretaceous, contains all of the workable lignite in North Dakota. Early students of the field referred part of the lignite beds to the "Fort Union" on paleontologic grounds. Reasons for retaining the distinction have not

[a] Upham, Warren, The glacial Lake Agassiz: Mon. U. S. Geol. Survey, vol. 25, 1895, p. 92.

seemed adequate, and the effort may well be abandoned. The Laramie is found over the region previously outlined as the lignite area, though its eastern border is buried, often deeply, by glacial drift. The difference in elevation of its deposits actually exposed within the State is at least 1,400 feet. Its greatest thickness, shown with certainty by the well at Medora to be more than 2,000 feet, occurs in the western part of the State, while its vertical extent gradually decreases toward the east till at the edge of the Coteau du Missouri it drops off sharply, beyond which it continues as a relatively thin series. The Laramie consists of clays, sands, sandstone, lignite, and thin bands of hematite, clay ironstone, and shaly limestone.

OCCURRENCE OF THE LIGNITE.

The numerous natural exposures of lignite in the driftless area and the remarkably fine opportunity to study the Laramie strata given by the badlands make it possible to draw, even from a preliminary study of the region, rather far-reaching conclusions in regard to the nature of the lignite beds. Five well-developed beds outcrop in the bluffs of the Little Missouri at Medora and may be traced for miles both north and south of this point. Along the Missouri south of Williston five or six beds show in a single section and can be traced for long distances, while on the Fort Berthold Reservation nine well-developed beds occur in a single exposure. The wells at Medora and Dickinson, a record of which is given in fig. 1, show an even greater number of beds. Near the eastern edge of the lignite area the number of beds is greatly reduced, but even here two or three exist at certain points, though generally but one is workable.

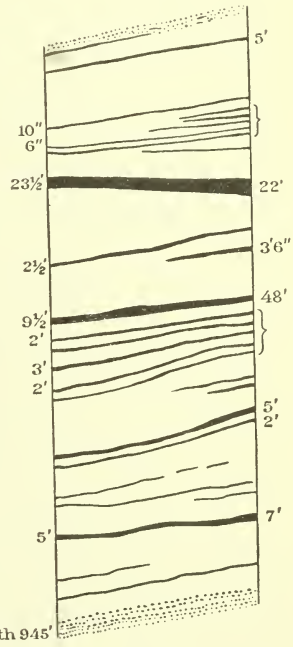

FIG. 1.—Diagram of lignite beds between Medora and Dickinson, N. Dak., by N. H. Darton.

On account of the nature of the beds, considered in a later paragraph, their number does not remain constant through large areas, and it is possible, though hardly probable, that at a few localities in the heart of the lignite area a prospect hole might pass completely through the Laramie, and not encounter a single lignite bed. This variation in number

and thickness of beds, often within comparatively short distances, will be a factor of great practical importance in opening up on a large scale a new lignite field. In the first place, it will increase the number of prospect holes that must be sunk to determine the amount of available coal in a given area. To offset this, however, are a number of conditions which make prospecting unusually easy.

Thickness of beds.—The lignite beds in North Dakota vary in thickness from an inch to 40 feet. This maximum thickness, which was carefully measured in the summer of 1902, occurs at an outcrop in sec. 31, T. 135, R. 101, which will be described in connection with the lignite on Little Missouri River. Three beds that reach a thickness of 25 feet are known, while beds 15 feet thick are not uncommon. In the western part of the State beds 2 and 3 feet thick are so common that in this report it is not practicable to note them minutely.

Extent of beds.—As important from an economic point of view as their thickness is the question of their persistence laterally. Attention was directed to this point, and the elevation of beds was noted in order to correlate, if possible, the beds exposed at one point with those at another. Generally such a correlation of beds distant from one another a number of miles was impossible on account of variations in thickness and elevation. While a single bed was often traced for 5 or 6 miles along the banks of the Little Missouri, another seen at the same time might thin out and give place to others above or below. The interrupted bed might begin again farther on after a break of half a mile or more, the lignite meanwhile being replaced by a bituminous or a nearly pure clay. The deduction, which early in the work seemed true, that certain horizons in the Laramie are much richer in lignite than others was not borne out by later observations. For a given locality the statement holds good, but a horizon which abounds in lignite at one point may be barren in another. A striking instance of the rapid thinning out of a bed is given by the 40-foot bed already referred to, which within one-fourth of a mile decreases to 17 feet, the top and bottom drawing together like the surfaces of a lense. Sufficient work has been done at one point near Minot to demonstrate the persistence of a thick bed beneath the greater part of a township, but this seems to be the exception rather than the rule. N. H. Darton has suggested a correlation of the beds encountered in the wells at Medora and Dickinson, but as the distance between these points is 39 miles, and lignite beds vary so greatly in order and continuity, the identity of the beds can not be established.

Variations in fuel value in a single bed.—A majority of the beds examined and tested show no great difference in fuel value from top to bottom. In some instances, however, the differences in the com-

position of the lignite in a given bed are considerable. Not infrequently the upper foot or two are inferior, and are left for roof in mining. The loss in this case is not as great as might be expected, for it is often more economical to leave coal for a roof than to timber. When the lignite lies directly under the glacial drift, as at the Hanchett mine, 10 miles southwest of Velva, the upper portion shows deterioration. Shaly layers sometimes occur, which if mixed with the coal from the rest of the bed raise the percentage of ash for the whole very considerably. Sulphur in any form is present commonly only in traces. Iron nodules, which prove so annoying to the operator of mining machines in the East, do not occur in the lignite, and there are no hindrances to the use of drills and undercutting machinery.

Variations in fuel value in different beds.—The chemical analyses of 70 samples from as many beds, given on pages 17 and 18, throw light on the fuel value of lignites from as many parts of the State. Samples were not taken from beds that were obviously too thin or too impure to be of economic value, but, on the other hand, all analyses made are given, whether favorable to the lignite or not. The lignites taken as a whole will probably average better than the samples analyzed indicate, for in many cases fresh material could not be obtained, and the weathering on the surface of a natural exposure is sufficient to lessen the carbon values for some feet from the surface. In the discussion which follows, lignites which are reported as good have between 40 and 50 per cent of fixed carbon and not more than 8 per cent of ash.

Possibilities of coal at greater depths.—There are no theoretical considerations to support the rather common notion that at greater depths a higher grade of coal exists. The analyses of the coals found by the railroads in the deep drillings in the western part of the State have not been examined, but as these borings were made some years ago and no development work has followed, the inference seems fair that bituminous coal in significant quantities was not found.

A popular fallacy in regard to lignite.—The belief so often expressed that lignite beds outcropping on slopes are certain to thicken is hard to account for. While in many cases the beds doubtless thicken away from the outcrop, the reverse will as often prove true. The lignite beds being in general lens-like, it is impossible without drilling to determine whether the outcrop represents a section near the edge of the lens or across the center. If the outcrop represents a section near the edge of the lens the lignite will thicken as the drift goes into the hill or bank till the center of the lens is reached, while if it is across the center the lignite will become thinner.

OUTPUT OF LIGNITE IN 1902.

Following is a summary of the output of the lignite of North Dakota mines in 1902:

Summary, by counties, of lignite output for 1902.

County.	Loaded at mine for shipment.	Sold to local trade.	Total product.	Total value.	Average spot value per ton.
	Short tons.	*Short tons.*	*Short tons.*		
Billings		5,000	5,000	$4,000	$0.80
Burleigh	120,000	10,000	130,000	169,000	1.30
Emmons		1,000	1,000	2,750	2.75
Mercer		3,000	3,000	2,400	.80
Morton	30,000	5,000	35,000	45,000	1.30
McLean		4,000	4,000	5,200	1.30
Oliver		3,000	3,000	2,400	.80
Stark	45,000	10,000	55,000	66,000	1.20
Ward	57,800	19,000	76,800	107,520	1.40
Williams		3,000	3,000	24,000	.80
Total			315,800	428,270	

FUEL VALUE OF NORTH DAKOTA LIGNITE.

The fuel value of a given lignite will vary considerably with the conditions under which, and the purpose for which, it is used. In one connection it may be esteemed highly and in another have no value at all. Out of this fact grows the diversity of opinion in regard to a number of well-known lignites of the State. A lignite whose value as a steam coal is very high may not prove suitable for certain kinds of stoves. An actual case will serve well for illustration. In two localities lignite from seams that are high in ash, due to admixture of clay, are highly valued for heating purposes, because the clay enables them to stand up well and prevents slacking. Judged by ordinary standards these lignites are very inferior. These recognized standards are: The amount of fixed carbon and the percentage of ash that the lignite contains, the result given by the calorimeter, and the amount of water that a given amount of lignite will evaporate. Of the three tests the last is the most satisfactory. The lignites have been tested in accordance with these, as well as in a variety of practical ways, and a brief statement of results is appended.

LABORATORY TESTS.

CHEMICAL PROPERTIES OF LIGNITE.

Fixed carbon.—The average amount of fixed carbon in 26 samples of North Dakota lignite analyzed in 1900, when thoroughly dried, was 52 per cent. Sixty samples, after thorough drying, gave 51.21 per cent of fixed carbon. Compilations of analyses of 41 samples of West Virginia bituminous coal show 67.16 per cent of fixed carbon; 22 samples of the better grades of semibituminous dry coals of Maryland show 75.99 per cent; and 26 samples of dry bituminous coal from Pennsylvania show 67.97 per cent. Judged by the fixed carbon alone the heating power of North Dakota lignite is 76 per cent of that of West Virginia bituminous, 65.9 per cent of that of Maryland semibituminous, and 74.4 per cent of that of Pennsylvania bituminous. These figures show that the North Dakota lignites rank far above the coals that are the average representatives of this class.

With respect to fixed carbon, the lignite of North Dakota appears to be equal to the product of the Western Interior coal field (which includes Iowa, Missouri, and Kansas). According to a recent United States Geological Survey report,[a] the amount of fixed carbon in 12 samples from the Western Interior field, computed on a dry basis, averages about 50 per cent. These coals, however, have a somewhat higher evaporative power than the lignites.

Volatile matter.—The average amount of volatile matter, exclusive of water, computed from 60 analyses of different lignite coals, is 35.63 per cent. When the fixed carbon alone is considered as determining the fuel value of a coal the worth of the volatile matter is overlooked. Under proper conditions these gases may be made to develop a great deal of heat, and no appliances which aim at an economical combustion of lignite can afford to disregard them.

Ash.—The percentage of ash in the 60 samples is generally low, the average amounting to 8.5 per cent. By deducting 4 inferior samples, the average will be lowered to 7.5 per cent. Compared with coals of the Iowa, Missouri, and Kansas region, lignites are notably purer. In the ash from some North Dakota coals there is a tendency to form clinkers, due to the presence of clay, but generally the lignite burns like wood, leaving a gray powdery residue.

Sulphur.—The percentage of sulphur in the lignites is usually

[a] Bain, H. Foster, Western Interior coal field: Twenty-second Ann. Rept. U. S. Geol. Survey, pt. 3, 1902, pp. 333–366.

low—much lower than in most bituminous coals. The following samples are fairly representative:

Percentage of sulphur in North Dakota lignites.

	Per cent.
Lehigh mine	0.88
Washburn mine	.91
Forty-foot vein, Billings County	1.10
Electric mine, Kenmare	.68
Davis mine (Mouse River Lignite Company)	.35

The sulphur in these analyses was determined in dry coal, which brings the percentage one-fourth higher than for lignite fresh from the mine. A yellow powder composed of calcium sulphate and iron oxide often occurs in the upper part of lignite seams and in color and texture resembles sulphur.

The average of 60 tests shows that the lignite contains 35.66 per cent of volatile matter and about 30 per cent of moisture. Several service tests of lignite show it to have an evaporative power of 4.2 pounds of water from and at 212° F. per pound of fuel. This amount is below the average test, but it is the amount used in computations for fuel value, and is 75 per cent of that of Iowa coal and 70 per cent of that of the Missouri product.

PHYSICAL PROPERTIES OF LIGNITE.

Moisture.—In a far larger measure than is the case with bituminous coal, the physical properties of lignite must be kept in mind in considering its fuel value. A series of analyses subsequently quoted shows that lignite fresh from the mine contains 30 per cent of moisture, in which respect samples taken from various parts of the State differ but slightly. When shipped under ordinary conditions and in the usual manner, the lignite reaches the engine room with nearly all of its moisture. Small samples that are more or less exposed to the air for two months reach the laboratory with from 10 to 20 per cent of moisture, as shown by the following tables, which give analyses of specimens in which no special effort was made to prevent drying.

The expense of shipping this moisture and its effect on the heating properties of the lignite are points worthy of careful study and experiment. The general opinion of those burning lignite is that if the lignite, in drying, did not fall to pieces, becoming so fine that it was apt to go through the grates, there would be great economy in burning it after drying, and that in those devices where powdered or fine coal is used the dry lignite presents a material saving over the "green." Theoretically, it would seem that this should be the case, for the heat necessary to volatilize the 30 per cent of moisture would be saved, and there is no apparent reason for a material loss of the volatile gases in drying.

In any case, if the coal could be dried before shipping and economically burned after drying, the freight charges would be reduced nearly one-third.

The so-called slacking of lignite is the process of crumbling that it undergoes when drying. It probably loses none of its fuel value in consequence, and there is probably a gain in this respect due to the absence of the moisture. Special conditions are necessary, however, to burn this fine coal advantageously, the danger being that it will fall through the grate or be blown out through the stack.

ANALYSES OF SAMPLES OF LIGNITE.

Analyses of lignite fresh from mine.

[Fixed carbon, volatile matter, and ash computed on dry basis.]

Mine and location.	Fixed carbon.	Volatile matter.	Ash.	Moisture.
Mouse River Lignite Co., Burlington:				
4 feet from bottom	51.28	35.83	11.89	32.00
Top	46.42	32.60	20.98	30.00
16 inches above clay seam	47.36	42.14	10.50	29.40
Lower 20 inches	52.96	38.93	8.11	34.70
Electric mine, Kenmare:				
4 feet from floor	57.95	34.41	7.64	32.90
3 feet from floor	59.19	36.56	4.25	35.00
Bottom	56.58	34.44	6.98	34.80
Top	56.87	36.58	6.55	34.80
Diamond mine, Kenmare:				
Top	52.98	37.24	9.78	33.00
Center	56.82	33.77	9.41	33.00
Lower 18 inches	56.97	36.28	6.75	33.60
Dakota Lignite and Brick Co., near Burlington	55.61	40.08	4.30	23.40
New Era mine, near Minot	57.66	38.22	4.12	33.60
Smith-Kenmare Dry Coal Co.:				
Next to clay	55.55	36.79	7.67	33.20
Next to roof	52.30	39.90	7.80	32.00
1 foot below roof	55.25	33.50	11.25	32.60
Wadeson mine, Sims	50.47	39.21	10.32	30.29
Lehigh mine	51.62	43.18	5.21	34.30
Satterlund mine, near Washburn	55.89	37.50	6.61	30.91
Washburn mine, at Wilton	54.93	38.75	6.32	31.82
Dickinson Brick Co	46.89	38.23	14.88	27.82
On Heart River, near Dickinson	60.49	38.31	1.20	14.25
Consolidated Coal Co., New Salem	53.86	41.66	4.48	27.48

Analyses of lignite partly dried.

[Fixed carbon, volatile matter, and ash computed on dry basis.]

Mine and location.	Fixed carbon.	Volatile matter.	Ash.	Moisture.
Sample from Beaver Creek, E. Williams County	57.97	38.34	3.69	18.13
Sample from Dry Fork Creek	48.99	35.81	15.19	16.26
Outcrops near agency at Elbowoods	57.29	37.29	4.76	19.97
Ed Hall's mine, near Fort Berthold Agency	51.41	35.16	13.43	17.63
Anderson mine, Stanley	50.95	38.40	16.65	20.36
Jones mine, 16 miles southwest of Balfour	53.77	37.72	8.51	21.73
Missouri River, west of White Earth River	51.60	43.04	5.36	13.33
Rose Hill mine, 15 miles southwest of Balfour	53.11	38.81	8.08	18.08
Opening, 8 miles north of White Earth	56.51	36.94	6.55	17.76
F. F. Alger mine, Stanley, Ward County	49.63	35.57	14.80	16.80
Pleasant Valley mine, Shell Creek	55.09	39.89	5.02	17.06
Sikes mine on the Little Knife	47.55	42.68	9.77	16.03
Badlands, 6 miles east of Fort Berthold	47.38	42.75	9.87	14.64
Boyds mine, sec. 17, T. 152, R. 94	55.18	37.85	6.97	17.63
Nesson opening	60.38	36.09	3.53	19.97
Williams opening, 5 miles south of White Earth	44.49	31.59	23.92	17.02
Gille-Miller mine	60.12	34.19	5.69	18.39
Sorenson mine, sec. 32, T. 162, R. 92	60.95	34.12	4.93	19.42
Pony Gulch mine, 16 miles southwest of Harvey	51.66	36.72	11.62	19.16
Leigh Ericson, Donnybrook	59.75	35.14	5.11	19.50
Lloyd Mining Co	58.23	33.13	8.64	17.08
Scribner's mine	56.61	36.87	12.52	16.23
Drift, near railroad bridge near Burlington	56.57	38.01	5.42	17.46
Turtle Gulch mine, sec. 14, T. 152, R. 81	53.78	37.20	9.02	20.02
Wm. Lacy's land, Coal Harbor	53.43	39.14	7.43	18.51
Hanchett mine, southwest of Velva	53.60	40.14	6.16	16.69
Coal Canyon, 30 miles south of Medora	52.47	38.57	8.96	16.79
J. C. Gamel's ranch, sec. 20, T. 133, R. 104	55.90	37.59	6.51	18.24
Sentinel Butte, Billings County	48.04	42.67	9.29	18.99
From 777 ranch on Little Missouri	43.47	34.55	21.98	14.54
Forty-foot seam, sec. 31, T. 135, R. 101	51.79	38.69	9.52	13.70
Lower vein on Missouri River, 3 miles south of Williston	50.65	36.15	13.20	10.56
Twelve-foot seam, 3 miles east of Williston	54.38	36.37	9.15	11.25
Heaton's land, sec. 29, T. 145, R. 80	54.59	39.49	5.92	11.04
Coal Lake mine, sec. 22, T. 146, R. 82	55.73	38.74	5.53	11.23
Reiss mine, New England	53.03	38.39	8.58	24.46
Stone-Bird mine, near Belfield	56.61	35.71	7.68	21.56
Average	51.21	35.63	8.50	.....

Number of samples in Tables I and II, 60.

Deductions.—The method of analysis employed differs from that commonly used for lignites, for the percentage of moisture is first computed and then, after the moisture has been expelled, the amount of the other constituents is determined. The percentage of fixed carbon, volatile matter, and ash is made somewhat higher than when the undried coal is analyzed. The practical difficulty in bringing the lignite to the laboratory without partly drying, however, makes it much more desirable to compute composition on a dry basis.

Even when allowance is made for this method of computation the percentage of fixed carbon is high enough, if this alone is considered, to remove these coals from the lignites and place them with the semi-bituminous or steam coals. The content of water, however, about 30 per cent, keeps them in the former class.

PRACTICAL USE.

EVAPORATIVE TESTS.

More satisfactory than either chemical or calorimetric tests are practical evaporative tests carried on with boilers of standard patterns. A number of such tests have been made, and in some cases eastern coal also has been tested in the same boilers and under practically the same conditions, so that, knowing the price of each coal at the point given, it is possible to determine definitely the economy resulting from use of lignite.

Tests under natural draft.—The following test was made at the asylum for the insane at Jamestown by Chief Engineer Thomas Pettigrew, whose careful study of proper methods for burning lignite has greatly advanced the lignite industry.

Test of lignite at insane asylum at Jamestown, N. Dak.

[Date of test: Youghiogheny coal, August 6, 1894; lignite coal, August 8, 1894.]

		Youghiogheny coal.	Lignite coal.
Duration of test	hours	7½	8
Average temperature of feed water	° F	74	74
Coal burned	pounds	1,400	3,370
Combustible	do	1,243	3,170
Ash	per cent	11.21	5.93
Coal burned per square foot of grate per hour	pounds	8.29	18.72
Total water evaporated at temperature of feed	do	8,837	14,157
Water evaporated in pounds per pound of coal actual condition		6.312	4.2
Water evaporated per pound of combustible	pounds	7.1	4.46
Temperature of flue gases	° F	510	510
Boiler 6 feet in diameter by 16 feet long, with 30 4½-inch flues; grate surface, 4 feet 5 inches by 5 feet; coal 3 days from mine; value of coal		$1.00	$0.665

The cost of Youghiogheny lump at Jamestown was $6.80 per ton and of lignite $2.80.

Test of Lehigh lignite made by the Missouri Valley Milling Company at Mandan, N. Dak.

Duration of test	hours	11
Kind of furnace		Smith-White.
Grate surface	square feet	30
Width of air space in grate	inch	¼
Water-heating surface	square feet	1,549
Ratio of water-heating surface to grate surface		51 to 1
Average steam pressure		104
Average temperature of feed water entering boiler	° F	175
Total coal fed to furnace	pounds	12,221
Moisture in coal	per cent	23
Coal consumed per square foot of grate per hour	pounds	37
Cost of coal delivered at mill per ton		$1.60
Total cost of coal		$9.77
Total weight of water fed to boiler	pounds	56,350
Water evaporated per hour from and at 212° F	do	5,554
Horsepower developed		163
Cost of fuel for evaporating 1,000 pounds of water		$0.1734
Average horsepower of engine		190
Cost per horsepower per hour		$0.0047

The mill has a capacity of 450 barrels of flour per day, and the cost of fuel, when lignite is burned, per barrel of flour ground is 4.46 cents.

Test of Wilton lignite coal in the Fargo-Edison Company's plant at Fargo, N. Dak., January 9, 1901.

Duration of test	hours	12
Boilers used: Two 16 feet by 72 inches tubular, one 200-horsepower Heine water tube.		
Total heating surface	square feet	4,823
Total grate surface	do	88
Average steam pressure	pounds	83
Average temperature of feed water	°F	140
Total weight of coal fired	pounds	26,400
Cost of coal per ton of 2,000 pounds at boilers		$2.60
Total cost of coal		$34.32
Total weight of water pumped into boilers and apparently evaporated	pounds	97,500
Water evaporated per pound of coal from average pressure and temperature	pounds	3.7
Equivalent evaporation from and at 212° F	do	4.1
Coal burned per square foot of grate per hour	do	25
Cost of fuel to evaporate 1,000 pounds of water		$0.352
Moisture in coal	per cent	30
Refuse in coal	do	3½

Boiler test of lignite at North Dakota Agricultural College, March 8, 1902.

Duration of test	hours	8.5
Average atmospheric pressure	inches	28.5
Gage pressure	pounds	73.8
Temperature of feed water	°F	144
Kind of fuel	"White ash" lignite.	
Moisture in coal	per cent	36
Description of boiler: Common fire tubular boiler, with 62 flues, 3 inches in diameter, 16 feet long; diameter of shell, 60 inches.		
Water-heating surface	square feet	962
Ratio of water-heating surface to grate surface		.025
Coal burned	pounds	3,907
Unburned fuel		None.
Average coal burned in fifteen minutes	pounds	144.91
Total refuse from coal	do	168
Total combustible	do	2,314.5
Average combustible for fifteen minutes	do	68.05
Quality of steam (saturated steam taken as unity)	per cent	0.97
Total water pumped into the boiler	pounds	1,236.5
Water apparently evaporated per pound of fuel burned		3.16
Water actually evaporated, corrected from moisture	pounds	11,994
Equivalent water evaporated into dry steam from and at 212° F	do	13,228
Equivalent evaporation into dry steam from and at 212° F. per pound of dry coal burned	pounds	3.385
Coal burned per square foot of grate surface per hour	do	18.38
Water evaporated from and at 212° F. per square foot of heating surface	pounds	1.606
Equivalent evaporation into dry steam per pound of combustible		5.68
Average ash	per cent	9.03
Combustible	do	90.97
Gas analysis:		
CO_2	do	7
O	do	6
CO	do	1.05

Test conducted by Lewis Larson.

In the foregoing tests natural draft only was used.

Test under forced draft.—On November 17, 1902, a preliminary test of lignite coal from the mine of the Kenmare Coal Company was made under boilers No. 1 and No. 3 of the State University heating plant. During the winter of 1904 more elaborate tests were made under boilers provided with lignite fire-brick arches and under boilers without arches, which it is hoped will settle the disputed question as to the real worth of these arches. For the test given below a steam calorimeter was not available, and the water fed to the boiler is assumed to have been evaporated. The boilers are fire tubular; diameter of shell, 54 inches. Each contains forty-eight 16-foot flues, with inside diameter of 3½ inches, and each contains 841.76 square feet of heating surface. They are provided with the

lignite fire-brick arches, and the test was made under forced draft from a fan.

Test of lignite at State University.

Duration of test	hours	12½
Percentage of moisture as shown by four days' drying	per cent	10
Percentage of ash	do	7.828
Evaporated per pound of fuel from and at 212° F.	pounds	4.307
Evaporated per pound combustible (coal minus ash and water) from and at 212° F.	pounds	5.242

With boiler and grate conditions about like those used in the test at the asylum for the insane, already quoted, three Iowa coals tested at Des Moines gave per pound of coal a water evaporation from and at 212° F. of 5.44, 5.21, and 6.52 pounds, respectively. Four standard Missouri coals gave 6.84, 6.27, 6.23, and 5.86 pounds, respectively. Comparing the results obtained from lignite with these—taking the evaporative powers of lignite at 4.2 pounds, which is conservative—the lignite appears to be worth 75 per cent of the Iowa coal and 70 per cent of the Missouri.

METHODS OF BURNING.

Automatic stokers.—In plants where considerable quantities of lignite are used automatic stokers with forced drafts give most satisfactory results. At the Fargo-Edison electric plant at Fargo stokers which burn the refuse from the Washburn mine, which consists of the cuttings of the mining machines and the fine coal incidental to blasting, are in successful operation and demonstrate clearly the ability of lignite to compete with eastern coal in the Red River Valley. The lignite, varying in size from dust to fragments of half a pound weight, is shoveled into hoppers and fed into the furnace by a screw 8 or 9 inches in diameter, the flanges being 6 inches apart. Forced draft is introduced into the ash pit. The cost of firing is greatly reduced and the fires are exceedingly uniform. Other forms of stokers are doubtless practical.

When an economic method of drying the lignite before shipping from the mine is found it will be possible to save 30 per cent of the freight. With automatis stokers, the reduction of the lignite to fragments in the process of drying will be advantageous.

Forced draft and arches.—On account of the gases, volatile at a moderate temperature, that lignite contains, special devices have been introduced in furnaces intended for its consumption, by which these gases shall be promptly raised to the temperature necessary to secure their complete combustion. For this purpose there is often built over the front of the fire box an arch of fire brick, which, becoming intensely hot, secures the combustion of the gases that come

in contact with it. That it is useful for this purpose there can be no question. The question remains as to whether it adds to the efficiency of the coal, since it shuts off a portion of the boiler from direct contact with the fire and interferes with firing, when fuel is fed with a shovel. To a certain extent the bricks themselves conduct heat to the boiler. The value of these arches is not fully demonstrated and the cost of their installation is considerable.

Forced draft is convenient if the plant is large, but lignite is giving excellent results in a number of plants where natural draft only is used. With forced draft a short stack is sufficient, and this saving over the construction of a tall chimney is often enough to pay for the installation of the fan. The forced draft is introduced into the center of the ash pit and there caused to spread out, so that it reaches all parts of the grate uniformly. Induced draft is not recommended for any purpose in connection with lignite, though a combination of forced and induced drafts seems to solve satisfactorily certain difficulties in burning brick.

Natural draft.—Very satisfactory results are being obtained with lignite and natural draft at the Minot electric-light plant, the Kenmare roller mill, and similar institutions throughout the State. With natural draft a large boiler and grate surface are desirable, though not absolutely essential, and more experience in firing lignite is necessary. The fires should not be allowed to fall off, for if green lignite is thrown into the furnace when the steam is falling, it acts like a blanket, and temporarily smothers the fire. Fuel should be added when the fire is high and by the time the steam gage begins to drop the fresh lignite has been dried and is ready to burn. It is a good plan to fire but one side of the furnace at a time.

Commercial use.—Two large flouring mills, at Mandan and Jamestown, use lignite exclusively for fuel. The plant of the Russell-Miller Milling Company, at Jamestown, a 500-barrel mill, uses a single boiler, 72 inches by 16 feet, with seventy-two 4-inch flues. Shaking grates, giving an area of 36 square feet with ½-inch air spaces, are used. Forced draft secured by a fan is employed, and 170 horsepower is maintained for twelve hours with the use of 7,600 pounds of Washburn lignite. The engine is a Corliss compound condensing, rated at only 165 horsepower. A careful test has shown that 3.73 pounds of Wilton lignite will maintain 1 horsepower per hour. With lignite at $2.45 at the mill, the cost of fuel per barrel of flour is 4.5 cents.

The Hebron roller mill burns 4 tons of lignite in twenty-four hours, with an output of 100 barrels of flour, besides custom work. Natural draft and ordinary grates are used.

The Kenmare roller mill, using a boiler 66 inches in diameter and 16 feet long, and grate with ⅜-inch openings, uses 161 pounds of slack lignite per hour to generate 40 horsepower, the steam pressure being 65 pounds.

The Washburn roller mill maintains 30 horsepower for twelve hours with 1½ tons of lignite. The boiler is 12 feet by 36 inches, and the engine small and crowded.

The New Salem Roller Mill Company is operating a 125-barrel mill to its full capacity. The boiler is 14 feet by 52 inches, and the engine is rated at 75 horsepower. Forced draft is employed. In twelve hours 3,700 pounds of lignite are burned.

The electric plant at Dickinson burns lignite under a boiler 72 inches in diameter and 17 feet long, using ordinary grates and forced draft, the fan being driven by a 2-horsepower motor.

The Minot Electric Light Company employs 2 boilers 16 feet long and 54 inches in diameter. Fifty horsepower is maintained for ten hours with 2 tons of green lignite. Natural draft is used, and the engineer does the firing also.

PUMPING WATER WITH LIGNITE.

By Charles S. Magowan.

The computations on page 26 indicate the amount of lignite that will be required to raise water to the level of the various flats found on the streams in western North Dakota.

DUTY OF WATER.

The first question that presents itself is that of the duty of water. In the absence of definite data on this point from North Dakota it is necessary to rely on the results of irrigators who have worked under somewhat similar conditions. Wilson[a] records that in Montana a second-foot serves about 80 acres, and that from 15 to 18 inches in depth during an irrigating season is believed to be sufficient. Mr. Wilson makes the general statement that 1,000 gallons per minute will irrigate from 5 to 10 acres per day, and in the course of a season about 100 acres. If water is supplied to a 10-acre tract at the rate of 1,000 gallons per minute for twenty-four hours, the depth of the water over the whole tract will be 5.58 inches. If water to this depth applied five times during the irrigating season is sufficient, a plant of this capactiy should care for 200 acres. This statement is made because it is desired to use 1,000 gallons per minute and multiples thereof in discussing pump efficiencies.

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[a] Manual of Irrigation and Engineering, 1903, pp. 55, 56.

CENTRIFUGAL PUMPS.

Centrifugal pumps only are discussed, since it is believed that in view of recent improvements that have been made in their construction no other pump can so economically handle large quantities of water under the given conditions, even for the higher lifts. The discussion is based on belt-driven centrifugal pumps, though some reference will be made to steam centrifugal pumping engines—that is, to machines where engine and pump are directly connected, being built on the same base.

The fuel that will be used in the locality under consideration is lignite that in service tests has been proved to have an evaporative power of 4.2 pounds of water from and at 212° F. per pound of fuel. This value will be used in the computations.

It is contemplated that engines will be used which will deliver at least 1 horsepower for every 35 pounds of steam furnished. This is a low-engine efficiency, and should be realized even under extremely adverse circumstances. By using engines of higher grade—and these should be employed with the larger pumps, where compound, condensing, triple-expansion, or even quadruple-expansion engines might be economically used—the efficiency would be more than doubled, the fuel consumption being correspondingly reduced.

EFFICIENCY OF PUMPS.

The accompanying table shows the capacities and efficiencies of centrifugal pumps of several sizes, all belt driven, together with the amounts of lignite that will probably be required to lift the water to various heights.

The per cent of pump efficiency noted in the table is obtained by comparing the amount of work realized with the amount of power applied to the shaft of the pump, and it is well to note that the efficiency increases as the capacity of the pump increases, thus favoring the installation of large plants.

The prices quoted are those furnished by manufacturers' agents, and are usually f. o. b. at Chicago or an eastern factory. A considerable range in price is noted, the difference being due to differences in weight, construction, and finish.

A new form of centrifugal pump known as the "Volute" is being placed upon the market at the present time, for which claims of increased efficiency are made, the claim being based on the increased care in the manufacture of the wheel and especially in the fitting of the runner, thus lessening the loss from "slip" otherwise sustained.

Capacities, efficiencies, and cost of centrifugal pumps, and amounts of lignite required to lift water to specified heights.

Number of pump (diameter in inches of discharge opening).	Capacity in gallons per minute.	Horsepower delivered to shaft of pump necessary to effect economical discharge at elevations of—				Efficiency of pump (per cent).	Tons[a] of lignite required to furnish power to operate engine and pump 24 hours when lifting the economical discharge to an elevation of—				Price of pumps (approximate) f. o. b.
		20 feet.	40 feet.	60 feet.	80 feet.		20 feet.	40 feet.	60 feet.	80 feet.	
6	1,050	11.8	23.6	35.4	47.2	45	1.2	2.4	3.5	4.7	$120-$280
8	2,000	22.0	44.0	66.0	88.0	46	2.2	4.4	6.6	8.8	190-390
10	3,000	32.0	64.0	96.0	128.0	47	3.2	6.4	9.6	12.8	240-570
15	7,000	70.0	140.0	210.0	280.0	51	7.0	14.0	21.0	28.0	400-840
18	10,000	100.0	200.0	300.0	400.0	52	10.0	20.0	30.0	40.0	700-900
20	12,000	120.0	240.0	360.0	480.0	53	12.0	24.0	36.0	48.0	900
24	15,000	130.0	260.0	390.0	520.0	58	13.0	26.0	39.0	52.0	[b]1,700
36	32,000	260.0	520.0	780.0	1,040.0	62	26.0	52.0	78.0	104.0	

[a] Price of coal in this region varies from 50 cents to $2 per ton.
[b] Volute.

With the assumptions made above the computations for the fuel consumption become so simple that the tabulation of them seems almost unnecessary. For example, consider a No. 15 pump delivering 7,000 gallons of water per minute against a head of 60 feet. From the table the number of horsepower required is 210, this multiplied by 35, the steam consumption per horsepower per hour, and this by 24, the number of hours considered, and the product divided by 4.2 times 2,000, the result is the number of tons of lignite consumed. In the above case the computation is as follows: $210 \times \frac{35 \times 24}{4.2 \times 2,000} = 210 \times \frac{1}{10} = 21.0$. Thus, in any case, the number of tons of lignite that must be supplied to the furnace equals one-tenth of the number of horsepower that is required to operate the pump.

It will be noted that the sizes considered are those that give capacities of about 1,000 gallons per minute or multiples thereof. It is also well to note that the capacity of any of these pumps can be very materially increased by slightly increasing the number of revolutions, but the efficiency will thereby be diminished.

Engines for operating centrifugal pumps must be capable of running at high speed, especially if the pump is operated against a high head. For example, a No. 6 pump operating against an 80-foot head must make 857 revolutions per minute; a No. 24 pump operating against a 20-foot head must make 190 revolutions per minute, and the engine, if directly connected, must work at the same rate. Builders of centrifugal pumps also build engines to meet these requirements and connect them directly to the pumps, especially for the lower lifts.

A No. 6 centrifugal pump capable of working against a 30-foot head can be bought for $520 or less, while a No. 8 pump that will work against the same head will cost $690. One firm quotes a price of $500 on a 30-horse-power, automatic, high-speed engine, and $1,675 on a 200-horsepower engine. These prices are for engines only. The companies will furnish on request prices on the larger sizes of steam centrifugal pumps.

Some large plants of this kind have been installed and are reported as working successfully. At Albany, N. Y., two 18-inch pumps operated by direct-connected, vertical, cross-compound engines lift 10,000 gallons each per minute, with a reported efficiency of pump and engine of 66.3 per cent, and with a net efficiency of the pump alone of 77 per cent, the lift being 21 feet.

RIVER FLATS AND LIGNITE.

MISSOURI RIVER.

YELLOWSTONE FLATS.

Area and soil.—On entering North Dakota the course of the Yellowstone is toward the northwest, then north, and just before uniting with the Missouri somewhat south of west, its total course in the State amounting to about 15 miles. For this distance it keeps close to the bluffs at the right bank of the valley, leaving broad benches unbroken by meanders on the left. Above the flood plain, which is covered with a dense growth of willows, is a wooded bench from 10 to 15 feet above high water, where large cottonwoods flourish. Its extent may equal 4,000 or 5,000 acres. Ten feet above this and 20 feet above the river at high water is the edge of a beautiful and extensive grassed terrace, which rises gradually for 2 miles to the foot of the bluffs, and which has an area of about 15,000 acres, below a contour line drawn 80 feet above the river. It is not cut up by ravines or gullies and a trench can be carried along the 80-foot contour with but few flumes. With such an initial head, water can be taken to almost any point on the flat.

The soil is a good loam and the upper terrace is already well grassed, though at present it yields hay regularly only where naturally irrigated by water that comes down in Fourmile and Eightmile creeks and other coulees and spreads out over its surface. Much of the woodland lies high enough above the river to be free from ordinary river floods, and is inundated only at rare intervals by the gorging of the ice. In all, at least 15,000 acres on the left bank of the Yellowstone in North Dakota may be regarded as suitable for irrigation if water from the river can be raised 80 feet.

The area in North Dakota is but part of flats that extend into Montana as far as Terry. The fall of the Yellowstone is but 2.7 feet per mile, and a slope of 1 foot per mile would probably be needed in a lateral ditch. A very long lateral would be necessary to take water from the Yellowstone and cover the flats if gravity alone is relied on.

Lignite.—Heavy beds of lignite occur near Sidney, Mont., on the Yellowstone River, 15 miles west of the North Dakota line. On the creeks which empty into the Yellowstone from the south, and notably on Charbonneau Creek, heavy beds of lignite are said to outcrop.

BUFORD-TRENTON FLAT.

Area and soil.—Extending along the north side of the Missouri from the State line to the eastern edge of old Fort Buford Reservation, a distance of 16 miles, is an extensive flat which needs only water to become highly productive. At Trenton station, in the middle of this tract, the river swings in abruptly till it is close to the bluff, narrowing the flat for one-half mile. Enough remains, however, to provide space for a waterway or a pumping plant, so that if water were available and irrigation seemed desirable the level bench both east and west of Trenton could be irrigated from a single station.

The flat includes about 12,000 acres, divided between an upper grassed terrace and a lower wooded bench, the former having about twice the area of the latter. The wooded bench is from 20 to 25 feet above ordinary high water and is said to have been flooded but twice in twenty-eight years, the last time in the spring of 1891. In places it is being cleared and cultivated. Although some portions are sandy, it has for the most part a good soil. The second or grassed terrace rises gradually from the edge of the wooded terrace, where it is about 30 feet above high water, to the bluffs, at the base of which it is 80 feet above the river. It has a strong gumbo soil which grows bluejoint or wheat grass, cactus, and sage when unirrigated, while with irrigation it produces both grass and grain abundantly, yielding 2½ tons of excellent hay to the acre. The Great Northern Railway crosses it, running at the foot of the bluffs, giving ready access to market for produce raised on it.

The efforts now being made by Mr. Edwin Jack and others to irrigate parts of this area are described on pages 50 and 51. It will be possible to irrigate a part of it as they are doing by building reservoirs and diversion dams in the draws that cut the bluffs behind the flat, but for a large part of it the economy of this method may fairly be doubted. For the area as a whole it will be advisable to consider the possibility of raising water from Missouri River.

Lignite.—Only limited quantities of lignite are known in the bluffs just back of this tract, though large beds may sometime be discovered. Two miles from Buford, in sec. 31, T. 153, R. 103, a 4-foot bed of good lignite is mined to some extent by stripping. About 75 tons were taken out in the winter of 1902.

On Eightmile Creek, above Jack's ranch, a 3½-foot seam furnishes some lignite, while fuel from Buford is in part brought from the Yellowstone and in part from the seams in Glass Bluffs, across the river. If a pumping station were established at Trenton, where the river cuts back nearly to the bluffs and divides the tract into two parts, it might be practicable to ship coal from the mines already opened near Williston, a distance of only 25 miles. In this case good lignite, f. o. b. at Trenton, will cost $2.50 per ton. The lift at this point, to cover the entire tract of 12,000 acres, will be about 70 feet, though a large part of it could be watered with a lift considerably less.

MUDDY AND MISSOURI RIVER FLATS AT WILLISTON.

Area and soil.—The Muddy is the main tributary of the Missouri from the east and north in North Dakota. Its drainage area includes nearly one-half of Williams County, or 700 square miles. In addition to a water supply from direct rainfall, it is fed by a number of perennial springs. On June 27, 1903, it had a flow of 18 second-feet, an amount said to be normal for that season of the year. Its valley is broad and, in the main, fertile. The bottom lands are often a mile wide, while a strip half a mile wide fit for irrigation may be counted on for 20 miles or more from its mouth. There may be 10,000 acres along the stream that could be irrigated if water can be found for so large an area. Along its tributaries there is much land not included in the above estimate, portions of which are already irrigated, mainly by diversion dams for spring flooding.

To be taken with the Muddy River flats are 3,000 or 4,000 acres on the Missouri between Williston and the mouth of the Muddy. It is probable that the amount of water that the Muddy annually contributes to the Missouri is more than adequate to water the 15,000 acres that lie near it, but it has not been demonstrated that a large reservoir can be economically located on the stream. Its valley for 15 miles is broad and seems to offer no point where a short wall can retain a considerable amount of water. If a dam were erected above this point, the water from some of the principal tributaries which empty below would be lost. The Fred Rounsaville dam, which was intended for a diversion dam rather than for a reservoir, is described on page 51.

Lignite.—There is an abundance of lignite on the Muddy and its tributaries, and along the Missouri below Williston.

The following banks have been opened up for local use about Williston, and on the creeks to the north:

The Mackersie bank on Sandy Creek, in sec. 6, T. 154, R. 101.

The Holland bank near Muddy River, 6 miles north of Williston, where a heavy bed of lignite is exposed.

The Lovejoy mine on Stony Creek, where a considerable bed outcrops near the Great Northern Railway.

The mine of the Pioneer Coal Company, which is more extensively developed than any of these, and is shipping lignite in considerable quantities. It is located on the railroad, which here follows the valley of Stony Creek, in sec. 26, T. 15, R. 100. The bed mined is 6 feet thick.

The Miller mine, located 4 miles east of Williston on Cedar Coulee, a tributary of the Missouri. A 12-foot bed here outcrops and will furnish a vast amount of excellent coal.

A number of lignite outcrops 4 to 6 feet thick, which occur along Cow Creek, a tributary of the Muddy, and are mined to some extent for local use.

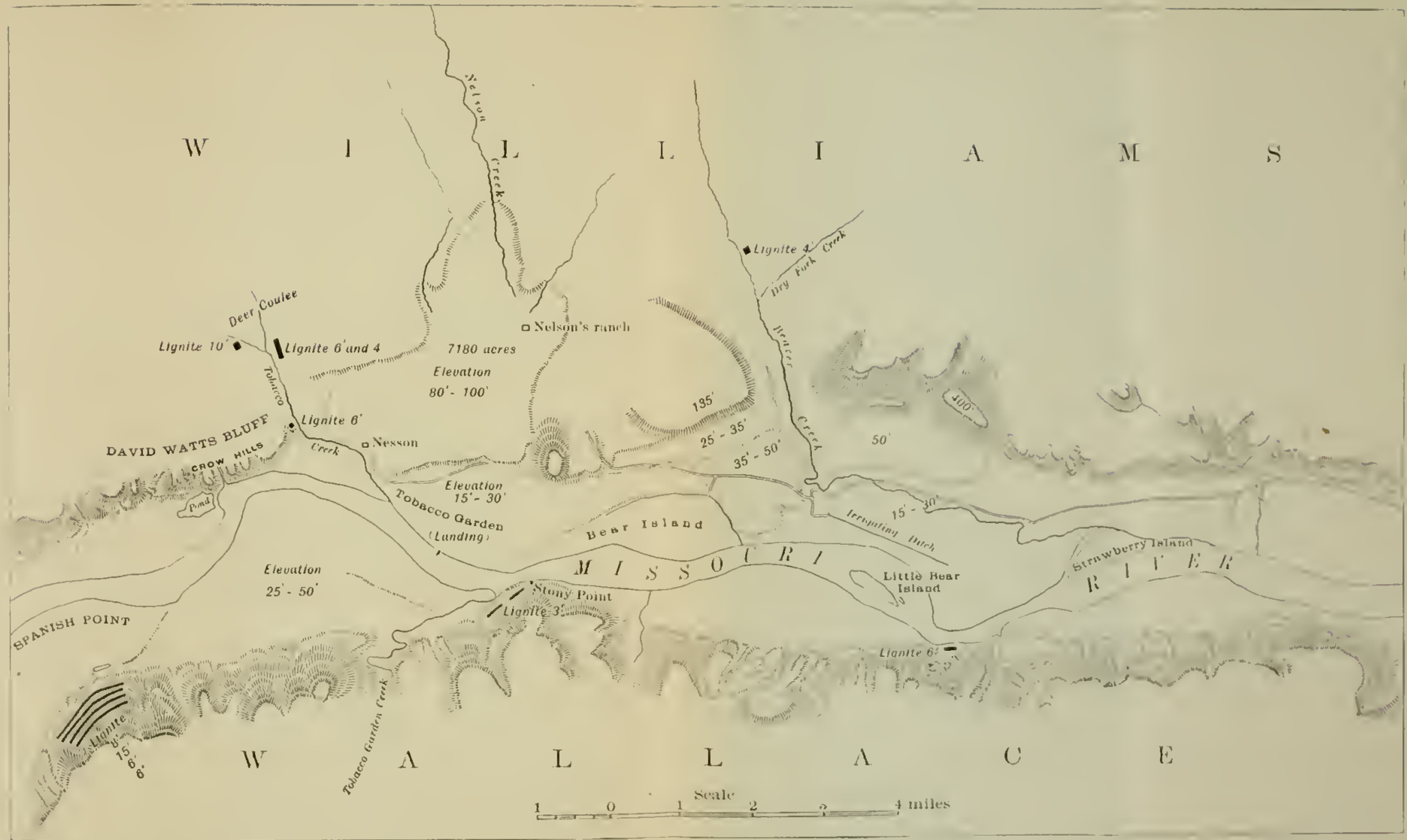
The old Dahl mine, 3 miles southeast of Williston, located on a 4-foot outcrop in the Missouri River bluffs on the left bank of the river.

Eight lignite beds, the heaviest being 4 feet thick, which outcrop in a single vertical section a mile farther down the river on the right bank.

NESSON-HOFFLUND FLATS.

The post-offices of Nesson and Hofflund are situated on Missouri River about 30 miles east of Williston and 14 miles south of the Great Northern Railway, the nearest station being the town of Ray; Hofflund is 6 miles east of Nesson. In this vicinity the Missouri receives a number of tributaries; Tobacco Garden and Clark creeks unite with it from the south, and Tobacco and Beaver creeks and White Earth River from the north.

Area and soil.—Two extensive flats or terraces are developed here, one from 20 to 40 feet above high water, extending about 6 miles along the river from Nesson to Hofflund, and the other from 80 to 100 feet high, located back of Nesson. The upper flat includes 7,500 acres held by more than 30 homesteaders and settlers; the lower includes about 6,000 acres. The soil of the upper, excepting a narrow gravelly strip along the lower edge, is composed of sandy loam with clay subsoil; that of the lower is of 1 to 4 feet of fertile sandy loam, with sand for a subsoil. Only a portion of the lower flat is wooded, the woodland at this point being confined principally to the flood



MAP OF NESSON-HOFFLUND FLATS.

plain, which is not here considered a part of the lower terrace. A portion of this terrace is being carried away by inroads of the river, but the loss due to this cause is not serious enough to interfere with any scheme for the development of the flat as a whole. The slope of the surface of both terraces is favorable to irrigation.

For many reasons the region invites study with reference to the possibility of irrigation. The area, especially when both terraces are taken together, is considerable, the soil is inviting, and the distance from a railroad shipping point in only 14 miles. Heavy seams of lignite of good quality outcrop in the immediate vicinity, and a pumping station that would furnish water for the lower flat (6,000 acres) may, it is thought, be placed close to one of these outcrops, and the expense of hauling fuel may thus be greatly reduced or wholly obviated.

Water supply.—On account of the lift it will hardly be practicable to irrigate the upper flat with water drawn from the river, but Tobacco, Nelson, and Beaver creeks may be considered as possible sources of supply.

Tobacco Creek, which unites with the Missouri at Nesson post-office, has a drainage area of 20 square miles, and is fed by strong springs. Cusack Springs, at the source of its west fork, in sec. 12, T. 154, R. 98, are perennial and flow 3 second-feet even in midsummer. Deer Coulee heads at a spring about as strong as the Cusack and unites with Tobacco Creek a few miles above Nesson. During the summer the creek suffers some loss of volume because of the porous nature of the stream bed at some points. On July 4, 1903, it had a flow of 5 second-feet at its mouth, an amount somewhat less than that of its spring sources.

At least two suitable reservoir sites seem to exist on Tobacco Creek, one occurring a mile back of the upper Nesson flat, where the creek emerges from the bluffs. Another site with apparently a larger capacity occurs 5 miles farther up the creek. However, the ability of the creek to furnish water enough to fill extensive reservoirs has not been demonstrated. Nelson Creek, which drains 40 square miles, could also be used, as it is now used in a measure, in irrigating the upper flat. It is spring fed, though the springs are weak, and most of its available water is due to the melting of snow. In another chapter the tracts at present irrigated in this vicinity will be noted.

Beaver Creek drains 120 square miles in the southeastern part of Williams County. On reaching the Missouri River flats it turns to the east and its bed gradually becomes ill defined, and at last its water is spread over the nearly level surface. Six miles above its mouth, on July 8, the flow was 18 second-feet, which was considerably more than the flow nearer the mouth. In the spring of an ordinary year the discharge is considerable. The descent of the

stream is rapid, and it seems possible to utilize the water, if it can be properly stored, to irrigate at least a part of the upper terrace.

The water from these three creeks seems sufficient to irrigate the 7,500 acres on the upper flat, which, on account of their elevation of from 80 to 100 feet, may not profit by any scheme to utilize the water of the Missouri.

On these creeks bowlders are fairly abundant. Aside from these, and beds of soft sandstone, no other stone occurs in the vicinity that could be used in reservoir construction.

Lignite.—For the lower flat, which includes 6,000 acres, pumping from the Missouri may be practical, for fuel is abundant, as shown by the following list of lignite outcrops that occur in this region. At Spanish Point, on the opposite side of the river and 4 miles farther up, four heavy beds outcrop in the bluffs. The aneroid gave the following elevations for the beds:

Relative altitudes of lignite beds near Nesson-Hofflund flats.

	Feet.
Top of bluff	2,850
Lignite, 3 feet, at	2,730
Lignite, 6 feet, good, at	2,690
Lignite, 15 feet, good, at	2,500
Lignite, 8 feet, good, at	2,450
High water of river, about	2,400

The elevations show merely the relative positions of the beds and may vary considerably from the absolute elevations. The bluff is one of the highest in the State.

On Deer Coulee, a tributary of Beaver Creek, at the Marmon ranch, 4 miles from Nesson, a 10-foot seam of good lignite outcrops, from which a strong spring issues. A seam of similar thickness is reported at a number of points at about the same elevation as this outcrop, and the bed may be regarded as rather extensive.

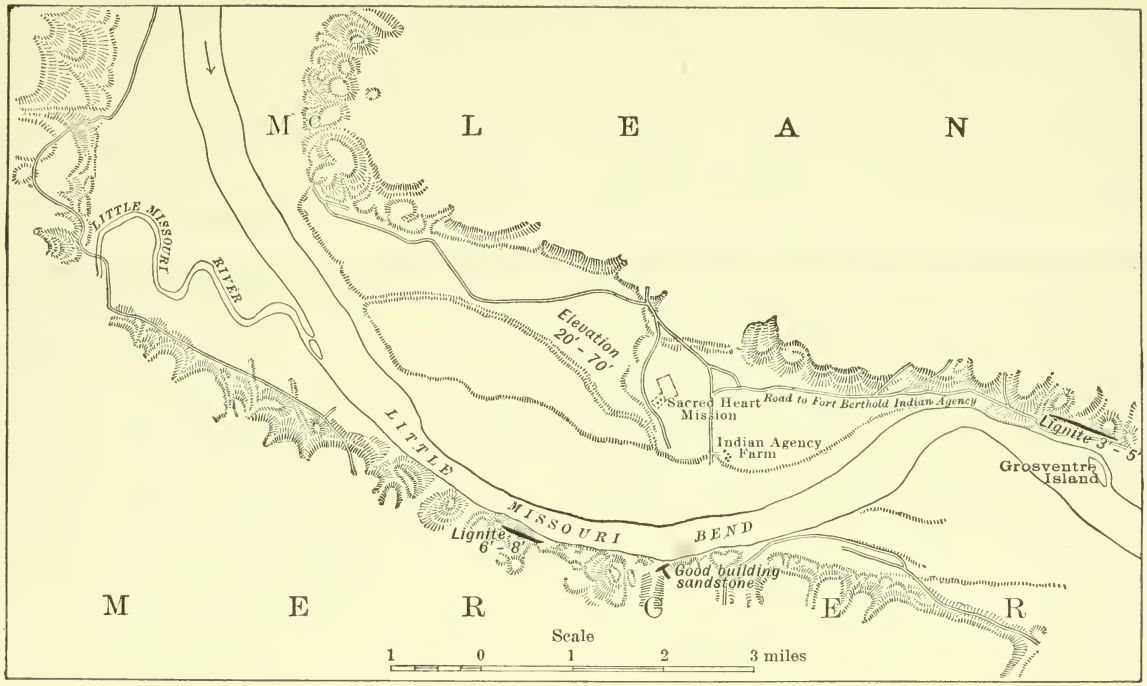
Along Tobacco Creek two seams, 6 and 8 feet thick, outcrop at a number of points, both seams often being exposed in the same vertical section. They can furnish large quantities of good lignite.

On Beaver Creek a 4-foot bed outcrops frequently and is used locally. Three miles above Hofflund a 10-foot bed is mined somewhat more extensively. An entry has been carried in 30 feet; this lies so low that in high water it is partly filled from the creek.

In the bluffs across the Missouri Mr. H. A. Carey takes coal from a 6-foot seam.

Lauchland's bank, located close to the west end of the lower flat, is said to show a good bed of lignite about 8 feet thick.

At Stony Point, on the right bank of the river between Nesson and Hofflund, two beds of good lignite, each 3 feet thick, were seen, and



MAP OF NEW FORT BERTHOLD AGENCY FLATS, ELBOWOODS, N. DAK.

a heavier bed is said to outcrop at this point. Pl. II illustrates the two flats and gives the location of some of the lignite outcrops.

FORT BERTHOLD AGENCY FLATS.

Area and soil.—The flats about the present agency on the Fort Berthold Reservation, which are low enough to justify study with reference to irrigation by pumping from the Missouri, include 5,000 acres. Of this perhaps 1,200 acres, which were formerly woodland and have been recently burned over, are now practically clear, while 800 acres are still covered with large trees. This woodland area is but 20 feet above high water, has a sandy loam soil, and is very rarely covered by water during ice gorges. Twenty feet above this lies a well-grassed flat of 1,200 acres, and still higher, perhaps 80 feet above the river, is a terrace containing about 2,000 acres.

Lignite.—Lignite outcrops frequently in the vicinity. Just across the river, at high-water level, a bed of 3½ feet of lignite was exposed; the whole bed was reported by the superintendent of the agency to be 10 feet thick. It has supplied coal for the agency during the winter when the river has been low and crossing on the ice possible.

In the bluffs 3½ miles below the agency and on the same side of the river a 9-foot bed with 1 foot of clay in the middle outcrops 50 feet above the low river flat. A half mile farther south the following section is exposed:

Section near Fort Berthold Agency, N. Dak.

	Feet.
Lignite, 6 inches of clay in the middle	6
Clay	20
Lignite	2
Clay	5
Lignite	2
Clay	50
Slope to low river flat	20

All of the lignite in this section seems to be good.

Seven miles below Fort Berthold Agency Mr. W. C. Dean reports a 12-foot bed of lignite, from which he hauls coal to the agency.

Lignite in beds of workable thickness outcrops in the bluffs back of Elbowoods at a number of points. The flats with lignite in the vicinity are shown on Pl. III.

OLD FORT BERTHOLD AGENCY FLAT.

This flat, which is about 12 miles below the present agency, contains about 4,000 acres, which are well grassed. Its elevation is from 20 to 80 feet above Missouri River, which bounds it on the

south. In the bluffs just east of the flat a 5-foot bed of good lignite is exposed about 50 feet above the river. On the opposite side of the river a 5-foot bed is mined by stripping. A 4-foot and a 3-foot seam outcrop in the bluffs a mile south of this mine.

FORT STEVENSON FLATS.

These beautiful flats, which include about 7,000 acres, lie on the north side of the river, a few miles northeast of Coalharbor (Pl. IV, A). Their elevation is from 30 to 70 feet above the Mis-

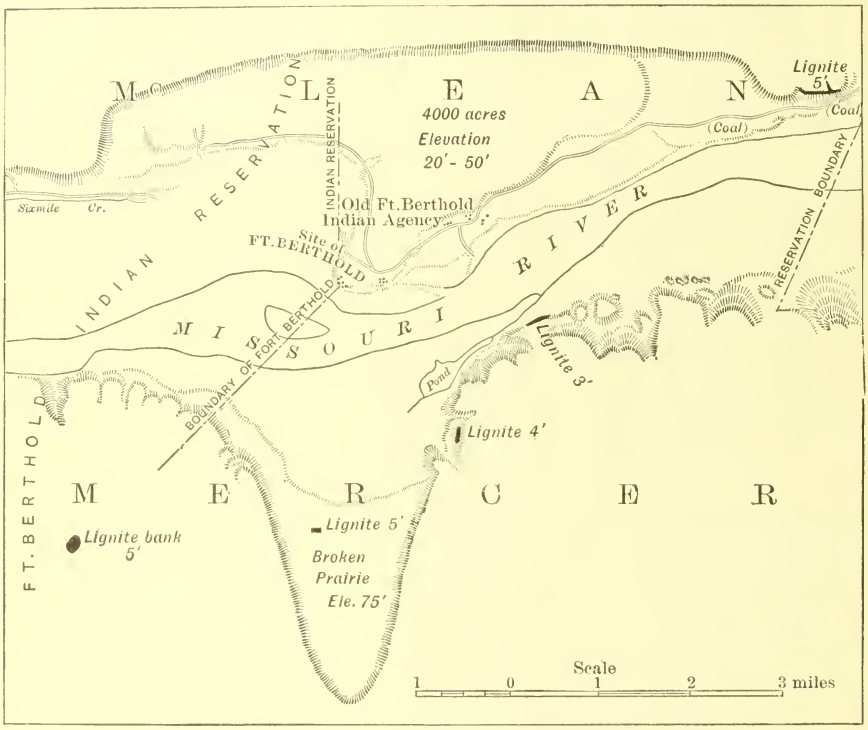
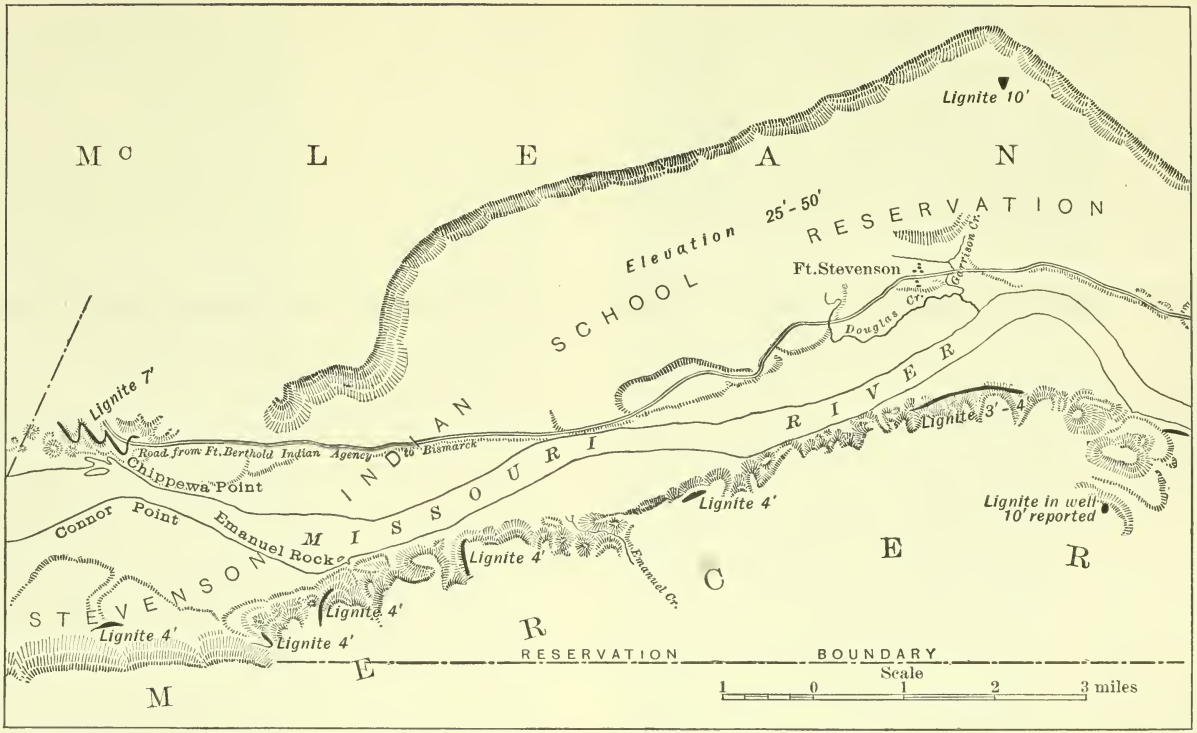


FIG. 2.—Map of flats about old Fort Berthold Agency, N. Dak.

souri. The slope from the bluffs to the river is gradual and uniform. Coal occurs abundantly in the bluffs just back of the flats. For many years lignite was mined here for use at the fort and the Indian school formerly located here. The exact location of the mine was SW. ½ sec. 35, T. 148, R. 85. A seam said to be 14 feet thick was mined by stripping. On the opposite side of the river seams 3 to 4 feet thick are nearly continuous in outcrop for 10 miles.

APPLE RIVER FLATS.

Just south of Bismarck are extensive triangular flats, which lie between Missouri River on the west, Apple River on the east, and the



MAP OF FORT STEVENSON FLATS.

A. A 5-FOOT LIGNITE BED ON THE MISSOURI ABOVE COALHARBOR.

B. SAGEBRUSH FLATS ON THE LITTLE MISSOURI.

bluffs back of Bismarck on the north. They have an area of about 5,000 acres, 2,000 acres being only from 20 to 30 feet above the river and partly wooded, while the rest are from 80 to 100 feet above river level. No coal outcrops in the immediate vicinity, but the expense involved in bringing lignite from the thick beds outcropping directly on the river 60 miles above, at Mannhaven and Coalharbor, should not be great. It may be more practical to control the water of Apple River and use it for irrigation purposes, for the stream drains a considerable area and could doubtless furnish all the water needed if it could be properly stored.

On account of their situation on the outskirts of a city of considerable size and on the Northern Pacific Railway gardening should prove remunerative, and a rather high cost per acre to secure irrigation may be justified.

BIG BEND AND SHELL CREEK FLATS.

Area and soil.—The Missouri River receives the waters of the Little Knife just before entering the Fort Berthold Reservation. Then, instead of pursuing its normal course, it makes a notable bend like a great letter U, which is known as the "Big Bend." Throughout this portion of its course, and in the valley of Shell Creek, which meets it at the lower end of the U, topographic conditions and heavy beds of lignite invite a careful study with reference to irrigation possibilities, though the conclusions that may be reached are probably more uncertain than in the flats already described. The area, however, is large, and as the land lies wholly within the reservation it is still completely under Government control.

The river at the "Big Bend" seems to have been diverted from its course at some time in the past, perhaps by the Wisconsin ice sheet, and compelled to cut a new channel to the west. Its former channel seems to connect the two arms of the U, and to form a valley 2 miles in width, with its center, a third of a mile wide, sloping very gently and unbroken by gullies. Its position with reference to the river and Shell Creek is shown on Pl. VI. At the upper end of the U this old valley is 140 feet above the river; its slope is toward the south, the upper half draining into a large slough in its center, while the lower portion contributes its water to Shell Creek. The area that could be irrigated advantageously, if water could be found, is two-thirds of a mile wide and 15 miles long and includes about 7,000 acres of good soil. In addition to this, on the Missouri at either end of this old valley are flats which contain 3,000 acres.

Lignite.—At the point marked A in Pl. VI, 6½ feet of good lignite outcrops in the bottom of a draw about 80 feet above the river without revealing the bottom of the seam. One-half mile down the

river in the bluffs at the point marked B, the following section is exposed:

Section at Big Bend, Missouri River.

	Feet.
Lignite	5.5
Clay	5.0
Lignite	7.0
Clay	50.0
Water level.	

One hundred yards farther down, a section partly covered by talus, gave:

Section at Big Bend, Missouri River.

	Feet.
Lignite	4.5
Clay	5.0
Lignite	3.0
Clay	50.0
Water level.	

The quality of the lignite in all of these beds is good.

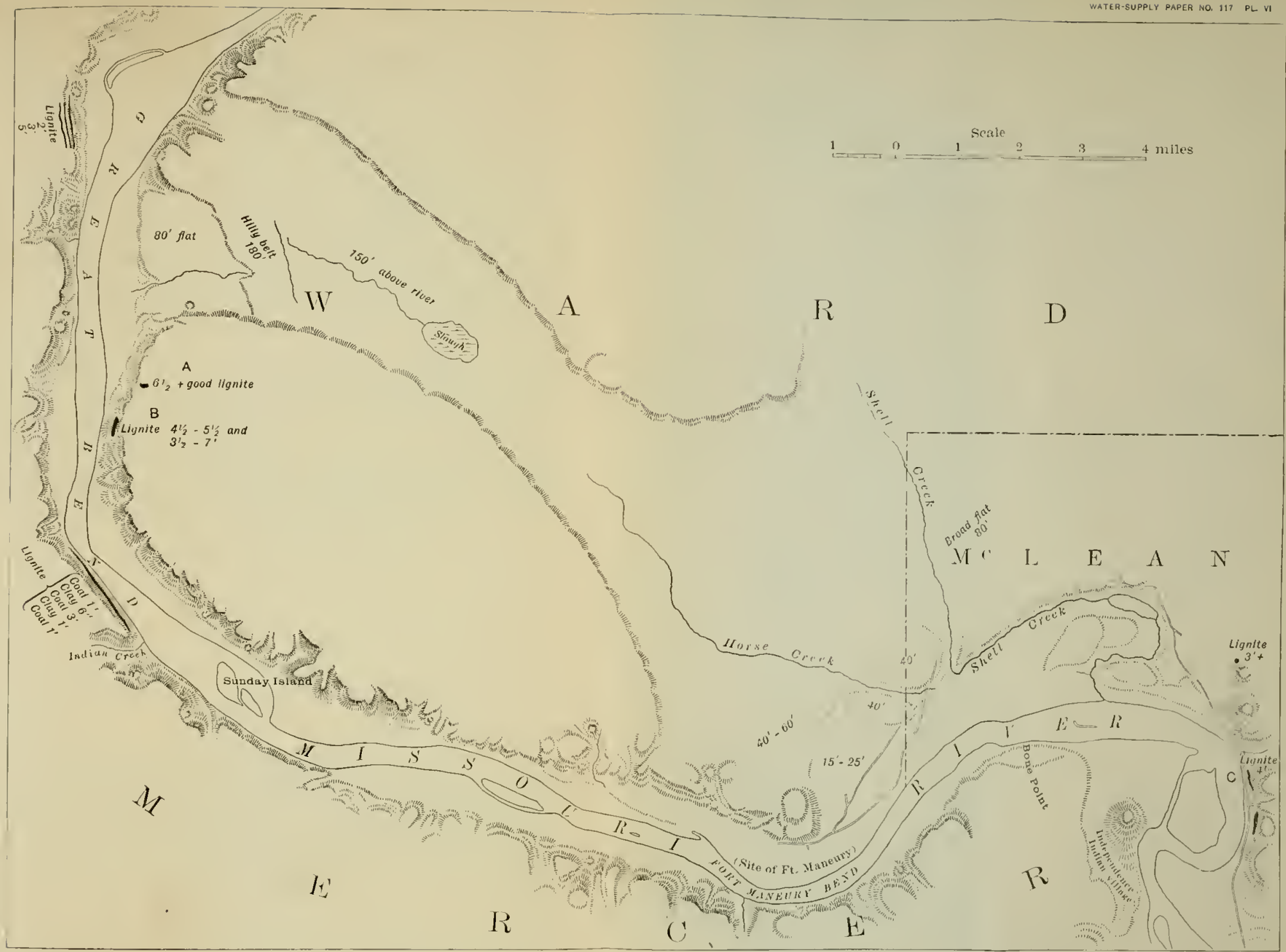
Just below Shell Creek, at the point C on the map (Pl. VI), 3½ feet of good lignite outcrops in a cut bank known as "the slide." This same seam probably gives rise to the spring in the bluffs 2 miles to the north, where the Indians have dug through 2 feet of lignite to give freer vent to the water. It is persistent in outcrop for 3 miles to the south, though showing but few good natural exposures. Although the exposures noted indicate a great abundance of lignite in seams from 4 to 7 or more feet thick, the amount of the lift may render pumping from the Missouri out of the question. Shell Creek drains more than 125 square miles, and its water may be available at least for portions of the area and for areas of 600 to 1,000 acres found along its own valley. The flow of water in Shell Creek on July 17, 1903, was about 6 second-feet.

OTHER FLATS.

Some of the many flats on the Missouri, limited in extent, but not so high as to render pumping from the Missouri out of the question, should be noted in addition to the more extensive tracts already described. Much of the woodland on the upper edge of the flood plain can doubtless be cultivated after clearing, since the soil is generally fertile and the value as timber land small. These tracts however are not included in the flats mentioned below.

On the south side of the Missouri, at the edge of the old Fort Berthold Reservation, there is a flat of 1,200 acres lying 40 feet above the river; no coal appears in the immediate vicinity.

On Muddy River cut-off, about 10 miles below Williston, on the north side of the river, are 700 acres, 20 to 40 feet above the river; lignite 6 feet thick shows in the bluffs a mile below.



MAP OF THE OLD VALLEY AT THE BIG BEND.

At Barkers Bend is a good flat of 600 acres; 12 feet of lignite appears in "sliding bluff" just below.

Opposite Nesson there are flats containing 1,200 to 1,500 acres from 25 to 50 feet above the river; the heavy beds of lignite in Spanish Point, already described, are only 3 miles away.

Opposite the mouth of White Earth River is an area of 600 acres; there are three lignite beds, the thickest 4 feet deep, in the bluffs just behind.

Opposite the mouth of the Little Knife are 2,000 acres in two terraces, one 20 the other 40 to 80 feet above the river; one lignite bed 4 feet thick was found in the bluffs behind this flat.

At the Indian village of Independence are 1,000 acres 80 feet above the river; lignite outcrops in a 4-foot bed just across the river.

Five miles below the mouth of the Little Missouri, on the east side, is an area of 500 acres in two terraces; lignite outcrops in a 4½-foot bed just opposite.

Just below the Fort Berthold Agency, on the opposite side of the river, is a long narrow flat containing 2,000 acres, 15 to 25 feet above the river, extending to Little Beaver Creek; 4 feet of lignite outcrop in the river bluffs at the latter place.

Just above the town of Mannhaven are 1,500 acres 40 to 50 feet above the river; 8 feet of good lignite outcrop on the river at Mannhaven, with thinner beds, as shown in the following section:

Section near Mannhaven, N. Dak.

	Feet.
Lignite, good	6
Clay	2
Lignite	1
Clay	1
Lignite, good	2
Clay	10
Lignite, good	8
Sand	12
Water level.	

This section may be seen for 2,000 feet along the river.

At Hancock are 1,500 acres in a series of terraces 15 to 25 feet above the river; 4 feet of coal outcrops in the bluffs behind, while across the river the heavy beds, once developed and known as the "Plenty" mine, outcrop. The beds there exposed show the following section:

Section near Hancock, N. Dak.

	Ft.	in.
Lignite	3	
Clay	0	6
Lignite	3	
Clay	2	
Lignite	3	

Mr. F. G. Mattoon is putting in a pumping plant to irrigate portions of these flats.

Two miles above Stanton, on the opposite side of the river, are 1,000 acres, 15 to 25 feet above water level; a 7-foot lignite bed outcrops near the water on the edge of the flat.

Opposite Washburn are 3,000 acres in three terraces, portions of which are subject to irrigation; 6 lignite exposures, showing from 3 to 7 feet of coal, occur in the bluffs and coulees behind the flats.

At Painted Woods Lake are flats containing 3,000 acres; there are 4 feet of lignite in a neighboring draw and a 5-foot bed exposed on a creek on the opposite side of the river near Sanger court-house.

At the mouth of Square Butte Creek, 8 miles above Mandan, flats occur; 2 feet of lignite are reported 2 miles to the north.

Near Mandan and at a number of points farther down the river are extensive flats; no heavy beds of lignite are known to occur near them.

LITTLE MISSOURI RIVER FLATS AND LIGNITE.

Terraces are well developed along the Little Missouri at nearly every point in its course. In a given locality their number may be five or six, and few localities have less than three. Their elevation varies from 20 to 200 feet above the river. No single tract is large, on account of the meandering of the river, but the total area at an elevation moderate enough to make pumping from the river practicable is considerable. A rather careful estimate of the area not more than 30 feet above the river places it at more than 30,000 acres, cut up into tracts ranging in size from 50 to 1,000 acres.

FLATS AND LIGNITE IN THE VICINITY OF YULE.

During the summer of 1902, 9 townships on the upper course of the Little Missouri, with Yule post-office as a center, were studied. There is much diversification in the topography of the country, which includes Little Missouri Valley and its terraces, the "breaks" in the vicinity of the river, and the rolling country back from the river, which furnishes an unequaled summer range for cattle.

Lignite.—Lignite outcrops almost continuously, even in the shallowest of coulees, as well as along the creeks and on the main stream itself. These outcrops are from 6 inches to 40 feet in thickness. Ranchmen seldom find it necessary to go far for fuel. Many of them consider it easier, however, to go to the river in winter and break up the great blocks of coal that the stream has washed out. There are a number of small flats on this stream south of Medora which lie well for irrigation by pumping. More than half of the area had not been surveyed in September, 1902, and it is impossible to cite locations definitely in many cases.

TOWNSHIPS 133 AND 138, RANGE 105.

In townships 133 and 138, range 105, which includes an area from 20 to 40 miles south of the Northern Pacific Railway, are the heads of a number of coulees, which flow eastward into Little Missouri River. In going from north to south, Williams, Garner, Bull Run, Horse, Coal Canyon, Cannonball, Boise, and Bacon creeks are crossed, in about the order named. All of these creeks show lignite more or less continuously from the time that they cut through the sod till they empty into the Little Missouri; their courses vary in length from 10 to 20 miles. None of them, except Cannonball, are shown on an ordinary map.

On Williams Creek, 6 miles from its mouth, the following section is given:

Section on Williams Creek, North Dakota.

	Feet.
Lignite, good	2
Clay	20
Lignite, good	4
Clay	4
Lignite, 1 foot exposed; bottom of bed not found.	

These beds were traced for a mile along the creek. Along the lower course of the stream lignite is said to be abundant.

On Garner Creek exposures of lignite are not abundant, though springs that probably come from the lignite are common, the lignite being concealed by the grassed slopes. A tributary which unites with the creek 8 miles above the Little Missouri is said to show a 4-foot bed.

On Horse Creek for more than 6 miles lignite beds varying in thickness from 3 to 6 feet are exposed at various elevations.

On Coal Canyon Creek an abundance of lignite is exposed along the deep ravine through which the stream flows. A typical section is as follows:

Section on Coal Canyon Creek, North Dakota.

	Feet.
Lignite, fair	5
Clay	1
Lignite, good	7
Clay	1
Lignite, good	1
Creek bottom.	

This exposure occurs 2 miles west of the Little Missouri.

On Cannonball Creek, which empties into the Little Missouri about 25 miles south of Medora and is a stream of some importance. its valley being nearly a mile wide a mile from its mouth, there are 6 feet of good lignite outcrop in a single bed. Along the Little Mis-

souri and its tributary ravines in this vicinity 4 or 5 beds of lignite may be seen, ranging up to 4 feet in thickness.

On Boise Creek, some miles above its mouth, 2 or 3 beds were seen, ranging from 2 to 4 feet in thickness.

On Bacon Creek, at the J. C. Gamel ranch, in sec. 20, T. 133, R. 104, a bed 24 feet thick outcrops. Its quality is good.

On Sand Creek a lignite bed 40 feet thick outcrops near the A. E. Russel ranch, in sec. 31, T. 135, R. 101. The exposure is continuous along the creek for a quarter of a mile, and much of the coal can be obtained by stripping less than 10 feet of earth from the surface. At the north end of the exposure the section given was:

Section on Sand Creek, North Dakota.

	Feet.
Sandstone	2
Clay	10
Lignite	2
Clay	2
Lignite	15
Clay	3
Water level.	

At the south end of the exposure the lignite reached the remarkable thickness shown below:

Section on Sand Creek, North Dakota.

	Feet.
Clay	5
Lignite	3
Clay	2
Lignite	40

The lignite throughout the bed appeared to be of good quality, except that the upper 2 feet were soft. The analysis indicates good quality.

On the Little Missouri near the 777 ranch, a few miles south of Yule, some fine beds outcrop. Rising directly from the water's edge at one point, the beds of clay and lignite reach a height of 110 feet, as shown in fig. 3. The heaviest lignite bed in the section is the lowest, which is more than 12 feet thick.

At Yule and at points between it and Medora 2 or 3 beds of fair thickness and quality occur.

Area.—Well-developed river flats occur along the Little Missouri in this vicinity, at times exceeding 500 acres in extent.

FLATS AND LIGNITE AT AND BELOW MEDORA, N. DAK.

In the Little Missouri Bluffs at Medora, on the Northern Pacific Railway, the section shown in fig. 4 may be seen. The lignite in all the beds is of good quality. It outcrops repeatedly on the west side of

the river. Both north and south of Medora for a number of miles lignite is as abundant as at the points cited. At some points, as near the Eaton ranch, it is mined for local use.

The larger flats along this portion of the Little Missouri are noted below, with the amount of lignite known to occur in their vicinity. The land has not yet been surveyed, and locations are noted by referring to ranches in the vicinity.

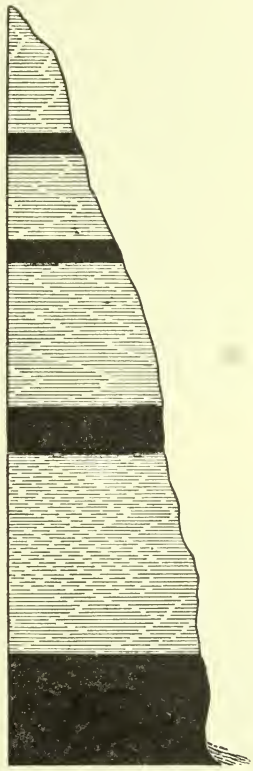


FIG. 3.—Section 30 miles south of Medora, at the 777 ranch, showing lignite seams.

Near the Burgess ranch, 4 miles north of Medora, are several flats from 50 to 160 acres in extent; lignite appears in three beds, each from 3 to 4 feet thick.

Between Burgess and Parkin's ranch, five miles north of Medora, are flats amounting to 400 acres, 100 acres of which are about 25 feet above the river; two lignite beds 4 to 8 feet thick appear.

Near Young's ranch are flats containing 400 acres; lignite occurs in large quantities on Government Creek.

From Young's to Johnson's ranch are flats containing 300 acres.

Near Mikkelson are flats containing 250 acres, 25 feet above the river, and 100 acres in addition in the vicinity; lignite is present in four beds, each from 3 to 5 feet thick; 2 miles below Mikkelson a 18-foot bed is exposed in a small butte. (Pl. VII, *B*.)

Near Carter's ranch, 3 miles below Mikkelson, are flats containing 250 acres and on the opposite side of the river 160 acres; lignite is abundant in the vicinity, a 9-foot bed outcropping 2 miles below the last-named flat.

Between Medora and the mouth of the Little Missouri several small flats ranging from 50 to 500 acres occur, which are from 15 to 30 feet above the water; lignite is abundant all along this portion of the river and is of good quality.

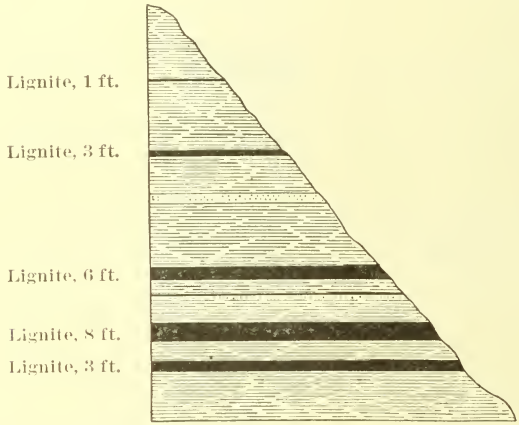


FIG. 4.—Section showing lignite seams in the bluffs at Medora.

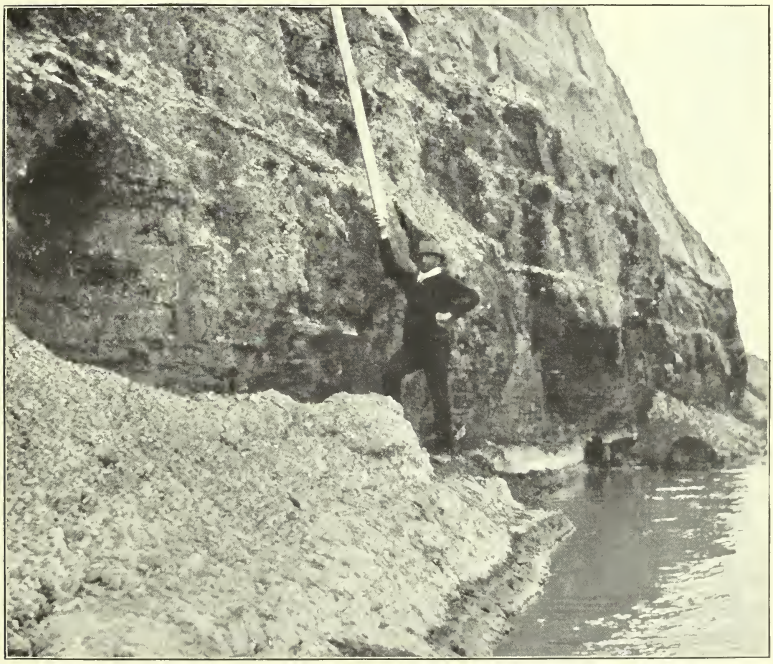
Near President Roosevelt's old ranch are flats which have an area of 200 acres; there is a 5-foot lignite bed in the adjacent draw.

Near Clark and Morgan ranches large flats occur at the mouths of Blacktail and Whitetail creeks, which here unite with the Little Missouri from the east; they include 400 to 600 acres, with a 10-foot lignite bed outcropping just across the river and 3- to 4-foot beds showing on the same side.

Near the mouth of Beaver Creek, both on this creek and on the Little Missouri, are large flats, the total area practicable for irrigation being more than 600 acres. (Pl. VIII, *A*.) Lignite in beds 3 to 4 feet thick may be seen at a number of points in adjacent bluffs.

Near Simpson's ranch and Magpie Creek is an area of 500 acres, from 15 to 25 feet above the river, broken into three tracts; two beds of lignite are exposed near by, each 3 feet thick.

A. AN 8-FOOT LIGNITE BED 8 MILES NORTH OF MEDORA.



B. AN 18-FOOT LIGNITE BED 2 MILES BELOW MIKKELSON.

Near Gore brothers' ranch are level flats containing 200 acres 15 to 25 feet above the river; lignite appears in two 3-foot beds.

Near Martin's ranch and Bolan and Redwing creeks is a 200-acre flat; there are lignite beds from 2 to 10 feet thick.

CHERRY AND TOBACCO GARDEN CREEK FLATS.

Area and water supply.—From the first permanent eastward bend of the Little Missouri northeast to the Missouri there extends an ancient river valley, drained by Cherry Creek into the former stream and by Tobacco Garden Creek into the latter, and also by the greater parts of Redwing and Bolan creeks.

This valley is indicated by broken lines on Pl. I; it seems to mark the course of the Little Missouri during some pre-Glacial period. It is about 30 miles long, and from 1 to 5 miles wide.

The highest point of the old valley is Bear Butte, which forms the divide between Redwing and Cherry creeks. Numerous tributaries, which carry considerable water in the spring, but are dry in the summer, enter both Cherry and Redwing creeks as they flow through the old valley. Most of these tributaries head in the divide between the Yellowstone and Little Missouri, and attain a maximum length of 4 or 5 miles. They are significant in connection with the irrigation of the valley, for land here is being taken under the desert land act, the intention being to irrigate by building reservoirs in the small tributaries to the creeks just named.

The bluffs back of the old valley are very abrupt. Under present conditions the most fertile portion of the valley is found on the upper part of Cherry Creek. The X ranch, owned by the Converse Cattle Company, grazed nearly 5,000 cattle on this portion of the valley during the entire summer of 1902. Irrigation by means of reservoirs in the tributary creeks and coulees is practicable to some extent.

FLATS AT AND BELOW FORT BERTHOLD.

After entering the Fort Berthold Reservation the flats on the Little Missouri become insignificant.

LIGNITE OUTCROPS.

A list of the more important lignite outcrops on the Little Missouri, and their position with reference to the river and flats, is given in the following table:

The more important lignite outcrops on Little Missouri River, North Dakota.

Location.	Number of beds.	Thickness in feet.	Extent of outcrop.	Elevation above river.	Distance from river.	Distance from flats.
4 miles from Medora, in buttes.	1	10	20 feet	225 feet	2½ miles	2½ miles.
Opposite Burgess's ranch	1	3	20 rods	River level	On river	40 rods.
	1	8				
2 miles below Burgess	1	5	4 rods	do	do	A few rods.
	1	6				
5 miles blow Burgess	1	3	Several rods	do	do	1 mile.
	1	5				
3 miles west of Parker's ranch.	1	3	do	8 and 15 feet	do	
	1	3				
3 miles east of Young's ranch.	1	3		200 and 300 feet.	3 miles	3 miles.
	1	10				
2 miles south of Mikkelson	4	17 to 18	10 rods	Near water	On river	1 rod.
2 miles north of Mikkelson	1	16	6 rods	Water line	do	½ mile.
Reed's ranch	1	8	Several rods	40 feet	do	Just across the river.
	1	10				
Mouth of Beaver Creek	1	3	1 mile	20 to 40 feet	do	Across river.
	1	8				
Near Morgan's ranch	1	3	do	River level	do	Edge of flats.
	1	7	½ mile	30 to 60 feet	do	40 rods.
	1	10	1 mile	30 feet	10 rods	80 rods.
Near Simpson's ranch	2	6 to 8	½ mile	0 to 60 feet	On river	Across river.
Bolan Creek	1	10 to 12		100 feet	1½ miles	2 miles.
	4	3 to 4				
Redwing Creek	1	10 to 12		do	1 mile	½ mile.
	1	4			On river	¼ mile.
Boehm's ranch	1	3 to 4	10 rods			Across river.
Squaw Creek	1	4 to 5	14 rods	300 feet	1 mile	½ mile.
	1	4 to 5	4 rods	200 feet	do	1 mile.
Near southwest corner Indian reservation.	1	12	2 to 3 miles			A few rods.
Near Manning's ranch	1	12	20 rods	10 to 20 feet	On river	40 rods.
	1	5 to 6	do		do	Do.

A. FLATS ON LITTLE MISSOURI RIVER NEAR BEAVER CREEK.

B. AN 8-FOOT BED OF LIGNITE ON LITTLE MISSOURI RIVER ABOVE REED'S RANCH.

FLATS AND LIGNITE ON KNIFE RIVER AND TRIBUTARIES.

FLATS.

Knife River.—The Knife River flats are like those along the Little Missouri just described, differing mainly in not being so shut in by high bluffs and in having the slopes to the uplands comparatively gradual.

The flow of water in Knife River even in summer is often considerable. On July 31, 1903, it was too deep to ford near its mouth, and when seen again at the same point on August 21 there was a foot of swiftly flowing water over the fords, which were 25 feet or more wide.

For 15 miles from its mouth the flats are extensive, often reaching a width of a mile and including in all about 4,000 acres, which lie from 15 to 25 feet above the river. Lignite is found along all the bluffs at the mouth and outcrops in nearly every coulee. An 8-foot bed is mined 4 miles south of the river on the west bank of Brody Creek.

Below Hazen the river flats within 4 miles embrace 2,500 acres. A 4-foot lignite bed is found 4 miles north of Hazen. From Hazen to the mouth of Spring Creek, the main tribuary of Knife River, a distance of 10 miles, are flats that lie 20 feet above the river and have an area of 2,000 to 3,000 acres.

From Broncho to Rock Springs, on Knife River, the average width of the flats is one-half mile, and the total acreage considerable. Four feet of lignite outcrop in sec. 14, T. 143, R. 94.

Spring Creek.—Flats extend up Spring Creek for a mile, above which to Halliday they are cut up into small tracts of 30 to 40 acres. Lignite in two beds outcrops near O'Neil's ranch.

From Halliday to Pelton's ranch, on Spring Creek, a distance of about 12 miles, flats are extensive and include about 4,000 acres. Spring Creek is perennial, and its flow is considerable. At Paulson's ranch a 16-foot bed of good lignite outcrops. It is covered by only 10 to 20 feet of clay, and furnishes fuel for the neighboring ranches. There is much coal in the vicinity of Halliday, as shown by springs and outcrops along the creek. At Olafson's ranch two beds of good lignite 2 and 3 feet thick outcrop on the north side of the creek. Six miles north of Halliday on Hans Creek a spring, which issues from a lignite outcrop, is used for irrigation. On the south side of this creek a bed said to be 10 feet thick is mined in winter.

Farmers Valley.—Farmers Valley, which extends from Hebron to a point north of Gladstone, and then north through Deep Creek Valley to Rock Spring post-office, contains 10,000 acres of land fit for irrigation if water could be found. In sec. 33, T. 141, R. 93, a possible reservoir site exists.

LIGNITE OUTCROPS.

The following table gives the more important lignite outcrops on Knife River and Spring Creek and their position with reference to river flats:

Lignite outcrops on Knife River.

Location.	Number of beds.	Thickness in feet.	Extent of outcrop.	Elevation above stream.	Distance from stream.	Distance from flats.
Sec. 9, T. 144, R. 89, G. Weige	1	5 to 6	10 feet		On creek	On edge of flat.
2½ miles east of Weige	1	10	20 rods	Taken on report; said to be on edge of flat and accessible.		
5 miles west of Weige	1	5	10 rods			Edge of flat.
Olafson's at Halliday	2	2 to 3	do		On creek	Edge of 200-acre flat.
Opposite Halliday	1	5	5 rods		do	Faces flat.
Sec. 15, T. 145, R. 92	1	4	4 rods		1 mile	
Anderson's, sec. 28, T. 146, R. 92.	1	[a] 10			7 miles	
Paulson's, sec. 27, T. 145, R. 93.	1	16	40 rods		On creek	Near 400-acre flat.
Paulson's, sec. 12, T. 142, R. 93.	1	5 to 6	5 rods	30 feet		Near 600-acre flat.
Corey's, sec. 28, T. 144, R. 96	1	4	Extensive			
Beck's, sec. 4, T. 144, R. 97	1	[b] 4		This bed is on Little Knife, between Fayette and Rickardton.		
Fayette	1 1	2 to 3 4	20 rods	Beds run along creek at elevation of 10 feet; 6-foot bed reported 6 miles west.		
Brannen's, sec. 34, T. 144, R. 99.	1	5		Placed upon the Little Missouri divide.		
5 miles south of Brannen's.	1	5		Extends along draw for several miles.		
Sec. 13, T. 141, R. 93, north of Richardton.	1	4				Near 600-acre flat.
2½ miles northwest of Richardton.	1	4				
Sec. 33, T. 141, R. 93	1	4				
Sec. 14, T. 143, R. 94	1	4	40 rods	20 feet	On creek	Do.
Sec. 13, T. 143, R. 94; O. Ziner's.	1	3 to 4				2½ miles.
Sec. 15, T. 143, R. 94; Bailey	1	4	5 rods		Near Knife River.	Near 1,000-acre flat.
Secs. 9 and 2, T. 142, R. 92; M. Hanson.	1	5 to 6				Near 600-acre flat.
Secs. 5, 7, and 9, T. 140, R. 90; Crowleys.	1 1 1	3 to 4 3 to 4 6 to 8				
Sec. 4, T. 142, R. 90; F. M. Smith.	1	4 to 5				Near 200-acre flat.
Sec. 14, T. 143, R. 89; Gerechts.	1	5 to 6				

[a] Reported. [b] At spring.

On the lower Knife River lignite is obtained at many points on the north side of the stream. The bed is 3 to 4 feet thick. Lignite may also be obtained from a bank 4 miles south of Hazen, where the bed is 8 to 10 feet thick.

FLATS AND LIGNITE ON HEART RIVER AND TRIBUTARIES.

FLATS.

Attractive flats, each containing a few hundred acres, may be found along Heart River and its tributary, Green River.

LIGNITE.

Heart River.—Lignite outcrops are frequent along both the Heart and the Green, some of the largest mines in the State being located in their vicinity. The New Salem mines, only 12 miles north of Heart River, had an output of 17,000 tons during the year 1902–3. Other mines at Sims, no farther from the river, are producing extensively. Between New Salem and the river 5-foot beds outcrop at a number of points and are mined on the strip-pit plan.

The mine of the Consolidated Coal Company at Lehigh, 3 miles east of Dickinson, has developed a remarkably fine bed of lignite

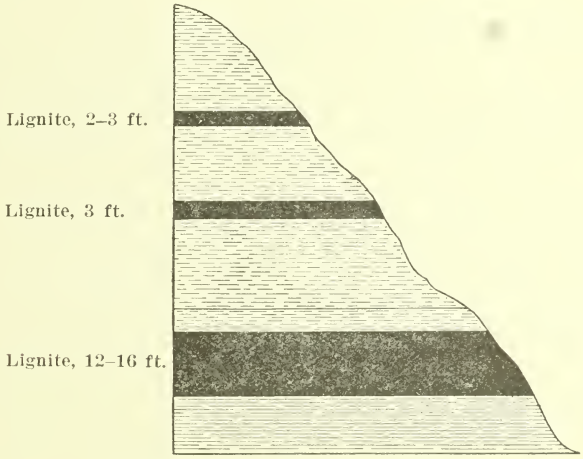


FIG. 5.—Section at the Lehigh mine.

which varies in thickness from 12 to 16 feet. It outcrops continuously along the river for 3 miles. Thirty feet above this thick bed a 3-foot bed is frequently exposed, and above this another and more variable bed. (Fig. 5.)

At two points on the outskirts of Dickinson lignite is mined in considerable quantities. At the plant of the Dickinson Pressed Brick and Fire Clay Company a 5-foot bed is mined by stripping. The Lenneville mine, half a mile east of Dickinson, shows a bed varying in thickness from 4 to 8 feet. Lignite from this mine ordinarily sells for $1.50 per ton at the mine.

Three and 4 miles west of Dickinson, on Heart River, a 4-foot and a 7-foot bed outcrop frequently. The lignite at the Bird-Stone mine, in sec. 6, T. 139, R. 98, outcrops on Heart River, and may be seen from the Northern Pacific Railway. The bed is 16 feet thick, the upper part being inferior in quality at the outcrop; the lower 8 feet is excellent. In section 8 of the same township the bed outcrops again. On the south side of the Little Heart, between South Heart and Belfield, a 6-foot bed of excellent coal occurs. It may be seen best in sec. 16, T. 139, R. 98, a school section.

Green River.—North of Dickinson lignite abounds on Green River throughout its course. Near its mouth at Gladstone beds of excellent quality, though not exceeding 5 feet in thickness, are found on the Rust and A. B. Powers farms in secs. 26 and 27, T. 140, R. 95. The exposures are directly on the river and near water level. Two miles farther up the stream, in W. ½ sec. 22, T. 140, R. 95, a 3-foot bed of good lignite is mined by the owner of the ranch on which it occurs. At the Kupper ranch, due north of Dickinson, a 15-foot bed of excellent lignite outcrops for a long distance on the edge of Green River. This bed is known to be very extensive.

Coalmine Creek.—Coalmine Creek, a tributary of Heart River, which unites with it a mile east of Belfield, shows great quantities of lignite along its course for at least 5 miles. Two good banks were examined, one 6 feet thick in sec. 28, T. 140, R. 98, the other 7 feet thick in sec. 27, T. 140, R. 98. A number of additional openings have been made along this creek from which lignite is taken. In sec. 30, T. 140, R. 99, 5 feet of a bed said to be 9 feet thick may be seen.

Norwegian Creek.—Three miles south of Belfield, on Norwegian Creek, a tributary of the Little Heart, which flows east and unites with the Little Heart 8 miles southeast of Belfield, a number of beds are exposed and slightly opened. They include the Englehardson bank, in sec. 20, T. 139, R. 99, with lignite 6 feet thick, and the Anderson bank in section 19 of the same township, with a bed 12 feet thick. In the vicinity of all of these lignite outcrops there are flats of moderate elevation.

FLATS AND LIGNITE ON CANNONBALL AND CEDAR RIVERS.

Terraces of different elevations, with a considerable total area, occur along the course of the Cannonball below its union with the Cedar and along both streams for 60 miles above their junction. On account of the meandering of the rivers, and the rather limited width of the terraces, more than 600 acres are rarely found in a single tract. With the data now at hand it does not seem practicable to irrigate areas larger than this by pumping from a single fixed station. It

may be, however, that detailed study will show that two or more of these tracts may be connected by ditches and treated as one.

CANNONBALL RIVER FLATS.

Area and soil.—The elevation of the Cannonball flats varies from 10 to 80 feet. The soil is generally fertile, and at many points is well grassed. In places it appears to be gumbo, while at others it is too sandy for agriculture. Taken together these flats have a considerable area, perhaps 30,000 or more acres, with soil and topography favorable for irrigation. As on the Missouri, there are opportunities to form reservoirs on the tributary streams and divert the water so controlled to the flats of the larger stream. The difficulties here, as there, will be found in constructing at reasonable expense reservoirs sufficiently strong to bear the water put upon them by violent storms.

Lignite.—Lignite is not abundant on the Cannonball below Wade post-office, where the Cedar unites with it. Only the following outcrops were noted:

Three feet of coal, reported in Castle or Palace Butte, about 6 miles north of Cannonball post-office, at the mouth of the river. Samples examined were of fair quality.

A 14-inch bed, mined by stripping, about 18 miles from the mouth of the Cannonball, in sec. 21, T. 134, R. 81. The outcrop occurs close to the river.

A bed 2½ feet thick, reported in a bank 4 miles northwest of Shields post-office, and an equal distance from the river.

A bed 18 inches thick, reported 3 miles north of Howe post-office.

A careful search made along the bluffs where good exposures occur brought to light only beds a few inches thick, till the upper Cannonball was reached.

Forty miles east of New England post-office heavy lignite beds outcrop, and appear continuously from this point for 50 miles up the stream. The following may be briefly tabulated:

Lignite beds on upper Cannonball River, North Dakota.

	Feet.
O. S. Chase bank, sec. 31, T. 134, R. 92	2–3, good.
E. C. Barry, bank, sec. 4, T. 133, R. 92	3, good.
Sec. 21, T. 134, R. 94	3, good.
NW. ¼ sec. 22, T. 134, R. 94	3, good.
Secs. 21 and 22, T. 135, R. 96	4, good.
Jacob Reiss bank, sec. 22, T. 136, R. 97	7, good.
John Ermintrout bank, 6 miles northeast of New England	3
Two beds, 5 miles west of New England	9, good.

COALBANK CREEK.

Lignite.—Coalbank Creek, a tributary of the Cannonball, which unites with it near New England, shows good lignite beds frequently; one 4-foot bed may be found 4 miles from the mouth of the creek.

CEDAR RIVER.

Lignite.—On the upper Cedar River lignite is said to be abundant, and judging from observations on the adjacent tributaries of the Cannonball the reports are probably correct. The same statement can be made for the upper Grand River in South Dakota.

PRESENT STATUS OF IRRIGATION IN NORTH DAKOTA.

A great part of the irrigation in North Dakota is due to the stimulus given by the desert-land act. The application of this law in the State seems to have been free from abuse, and a further application of it has been prevented by the fact that extensive areas in the semi-arid portion of the State are not recognized as desert land by the land offices. The only part of the State where desert-land claims may be filed is the northwestern, and here there is always some uncertainty as to what the ruling of the land office will be till each claim is finally inspected.

FLATS PARTLY IRRIGATED.

YELLOWSTONE FLATS.

On the Yellowstone flat in North Dakota, and just over the line in Montana, the following claims have been filed:

Andrew F. Nohle: Reservoir on Fourmile Creek, a tributary of the Yellowstone in Montana, near the boundary line. Fourmile Creek is said to have a drainage area of 24 square miles. The Nohle dam when completed will be 20 feet high in the center, and the reservoir when filled will have a surface area of 388 acres.

A. W. Mann: Claim in SE. ¼ sec. 31, T. 152, R. 104. He purposes to obtain water from draws in the bluffs behind.

Sarah and Kate Mercer: Desert claims on NW. ¼ sec. 32, and NE. ¼ sec. 31, T. 152, R. 104. They obtain water from draws. The main ditch to control these areas is already constructed.

BUFORD-TRENTON FLATS.

On the Buford-Trenton flats Mr. Edwin Jack (post-office, Trenton) has been foremost in the effort to secure water for irrigation. Associted with him are Carl Wittmeier, Grant Conley, and Charles Schumaker. A dam on Eightmile Creek, which comes down from the

north and spreads out over the Missouri bottom lands 3 miles west of Trenton, has been constructed across the creek bed. The reservoir so formed has a surface area of 75.4 acres, and a capacity of 521.5 acre-feet. The dam, which is of earth faced with stone, has a suitable flume and waste gate. Its present capacity is regarded as sufficient, aided by the rainfall and inflow during the irrigating season, to care for 400 acres. The dam has washed out twice and has been rebuilt each time in a more substantial manner. Up to the present about $8,000 have been expended on reservoir and ditches, with results which have satisfied the owners that the outlay is justified. The capacity of this reservoir could be increased considerably without great expense, and it is probable that water from Eightmile Creek would still fill it if its capacity were not much above 1,000 acre-feet.

MUDDY RIVER FLATS.

The most notable attempt to irrigate in the vicinity of Williston was made a few years ago by Mr. Fred Rounsaville of that place. Ten miles above Williston, in sec. 5, T. 153, R. 100, he constructed a dam to divert the water from the stream and throw it into a lateral ditch, which would irrigate the flats on the right bank of the Muddy, and possibly a portion of the flats at its mouth on the Missouri. No attempt to store the water was included in the plan. The dam was constructed and a portion of the ditch, when the work was stopped by the death of Mr. Rounsaville. The property is now offered for sale.

On the Muddy above Williston and on its tributaries the following irrigation work is in progress, the operations for the most part being limited to spring flooding for grass:

George Marelius and Stephen A. Marmon have a reservoir in T. 151, R. 101, on Blacktail Creek, a tributary of the Muddy from the west. They are said to be flooding 1,200 acres for both grass and grain.

The Freeman family are constructing a reservoir on the upper course of the Muddy, in secs. 20, 23, 29, and 30, T. 158, R. 100, where they are planning to irrigate 1,900 acres.

Ellen Adams has a desert-land claim, which is now proved up, in secs. 28 and 29, T. 155, R. 98. Water is taken from coulees that are dry in summer, and the irrigation is for grass only.

Joseph Langford is irrigating 300 acres in secs. 21 and 27, T. 157, R. 100, on the upper Muddy.

F. R. Zahl and his family hold a section, which he irrigates for grass, in secs. 24 and 25, T. 159, R. 101, at the mouth of Scoria Creek, a tributary of the Muddy.

L. L. and Howard Lampman irrigate two sections on Cow Creek, a tributary of the Muddy, in T. 156, R. 102.

James Sherry, on Stump Creek, a tributary of the Muddy from the west, irrigates a 20-acre garden in sec. 2, T. 156, R. 102, by pumping from a reservoir in the creek. During the year 1903 he pumped only 4 days, this, with the rains, being enough to mature a full crop of garden truck. An 8-horsepower gasoline engine lifted 800 barrels an hour 20 feet. With gasoline at 30 cents a gallon, the cost of operation per day of 10 hours was $3. The owner estimates that with the rain of an ordinary year to assist, his plant is capable of irrigating 160 acres. The soil is a sandy loam with clay subsoil. The cost of pump, pipes, and engine delivered at Williston was $811. Mr. Sherry has great faith in the profit to be derived from the enterprise, and next year will extend the area that he irrigates.

Mr. E. A. Sharp, on his farm 2 miles northeast of Williston, in secs. 17 and 20, T. 154, R. 100, is installing a 10-horsepower gasoline engine and a centrifugal pump, which, for his lift of 10 feet, has a claimed capacity of 735 gallons a minute. He intends to irrigate for grass and grain. Water will be taken from Stony Creek and Muddy River. He estimates that he can irrigate 200 acres with his plant, and that 30 days will be a maximum time for operation in an ordinary year.

Joseph Langford has 320 acres in secs. 21 and 27, T. 157, R. 100, which he irrigates from the Muddy.

The Hedderick ranch (formerly the Voss) irrigates extensively for grass at the mouth of Cow Creek, on the Muddy flats.

R. M. Calderwood, Grant Greenup, Francis Hendrickson, and others have filed desert-land claims on Camp Creek, in T. 151, R. 102, and have made preparations to irrigate extensively.

LITTLE KNIFE FLATS.

Mr. Black has irrigated with profit for grass at the mouth of Little Knife Creek for a number of years.

NESSON-HOFFLUND FLATS.

The Nelson ranch, at the mouth of Nelson Creek, on the upper terrace at that point, is an illustration of the possibility of irrigating like land at a moderate cost from the creeks coming down from the upland. An earth dam at the mouth of Nelson Creek diverts the water and laterals spread it over a considerable area so that 600 acres or more are flooded in the spring. The ground is thoroughly soaked to a depth of 2 feet and is then allowed to stand a week before cultivation. On land so prepared oats often yield 60 bushels to the acre and wheat 25, while the surrounding country, as favorably located except for the flooding, yields from nothing to 10 bushels.

One of the earliest attempts at irrigation in North Dakota was made at the old Grinnell ranch, at the mouth of Beaver Creek, where by dams and ditches the water from the creek was spread over several hundred acres of the lower Hofflund flat. Part of the same area is irrigated in the same way by H. A. Carey. Carey's dam is 20 feet high and is not intended to store water in the creek bed back of it to any considerable extent but to divert it to the laterals during the abundant water supply of the spring.

Ole Barsted has a dam and ditch on Dry Fork Creek, near its junction with the Beaver. Higher up on this creek are the dams of Wallender and Manly Anderson.

Nels J. Camp, William Barsted, and George Littlefield are diverting water for irrigation on Beaver Creek above Carey's.

Ward is irrigating the east end of the lower flat at Hofflund, at the old Lampman ranch.

HANCOCK FLATS.

Mr. F. G. Mattoon is putting in an extensive pumping plant to irrigate a portion of the fine flats on the Missouri at Hancock.

HEART RIVER FLATS.

Fisher Brothers, on Green River, a small tributary of the Heart, 7 miles north of Dickinson, have irrigated for two years, pumping water from the river. The lift is 15 feet, and a centrifugal pump with a discharge pipe having an inside diameter of 8 inches is used. A temporary dam 10 inches high and 30 feet long was thrown across the river in 1901 and retained all the water needed to irrigate 40 acres. In 1902 an abundance of rain made irrigation unnecessary. With this pump, which is driven by an ordinary farm engine, 1,500 gallons per minute are easily raised 15 feet. The cost of the pump delivered was $250. Mr. Fisher estimates that even in a dry season he would have no difficulty in irrigating 200 acres with his present equipment. Two dollars worth of coal was burned per day, coal costing 50 cents per ton at a neighboring bank.

Mr. A. F. Riley, on Heart River, near Gladstone, last year irrigated 20 acres by means of a dam thrown across a draw. Next year he proposes to irrigate 60 acres by means of a centrifugal pump. Lignite occurs on his farm, outcropping in a 4-foot seam, and can be had for the mere labor of mining.

RECOMMENDATIONS.

Opportunities to reclaim arid lands appear to exist in the larger flats on Missouri River. Much of the land in these flats is, however,

already in private ownership, that lying within the Fort Berthold Reservation forming the only exception.

In choosing among the Missouri River flats for one where reclamation by pumping may be tried under most favorable conditions, a number of factors must be kept in mind. Nearness to a railroad and a market are as essential as an abundance of cheap fuel and good land. An active interest on the part of the resident owners is necessary where the land is already in part or wholly private property.

With these conditions in mind, the Buford-Trenton flats and the Nesson-Hofflund tract deserve first consideration. The former lie directly on the railroad, but lignite is not abundant near by and will cost about $2 per ton, whether mined in the vicinity or hauled from Williston. The Nesson-Hofflund flats are 14 miles from a railroad and are wholly in private ownership, but, on the other hand, lignite is very abundant near them and should be laid down at the pumping plant for $1 per ton; it may even be possible to locate a pumping plant within a few hundred yards of an extensive outcrop. From an engineering point of view, the Buford-Trenton tract appears so offer simpler conditions.

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Water-Supply and Irrigation Paper No. 118

Series { B, Descriptive Geology, 56
O, Underground Waters, 33

DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

GEOLOGY AND WATER RESOURCES

OF

A PORTION OF EAST-CENTRAL WASHINGTON

BY

FRANK C. CALKINS

GOVERNMENT PUBLICATIONS

WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

PUBLICATIONS OF UNITED STATES GEOLOGICAL SURVEY.

The publications of the United States Geological Survey consist of (1) Annual Reports; (2) Monographs; (3) Professional Papers; (4) Bulletins; (5) Mineral Resources; (6) Water-Supply and Irrigation Papers; (7) Topographic Atlas of the United States, folios and separate sheets thereof; (8) Geologic Atlas of the United States, folios thereof. The classes numbered 2, 7, and 8 are sold at cost of publication; the others are distributed free. A circular giving complete lists may be had on application.

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WS 74. Water resources of the State of Colorado, by A. L. Fellows. 1902. 151 pp., 14 pls.
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WS 93. Proceedings of first conference of engineers of the reclamation service, with accompanying papers, compiled by F. H. Newell, chief engineer. 1904. 361 pp.
WS. 117. The lignite of North Dakota and its relation to irrigation, by F. A. Wilder. 1905. — pp., 8 pls.

The following papers also relate especially to irrigation: Irrigation in India, by H. M. Wilson, in Twelfth Annual, Pt. II; two papers on irrigation engineering, by H. M. Wilson, in Thirteenth Annual, Pt. III.

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The following paper also should be noted under this heading: Reservoirs for irrigation, by J. D. Schuyler, in Eighteenth Annual, Pt. IV.

[Continued on third page of cover.]

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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

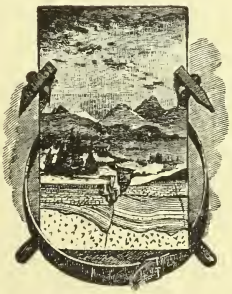
GEOLOGY AND WATER RESOURCES

OF

A PORTION OF EAST-CENTRAL WASHINGTON

BY

FRANK C. CALKINS



WASHINGTON
GOVERNMENT PRINTING OFFICE
1905

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., June 18, 1904.

SIR: I have the honor to transmit herewith, for publication in the series of Water-Supply and Irrigation Papers, a report by Mr. Frank C. Calkins on the water resources of a portion of east-central Washington, made in connection with the investigation of the underground waters of the Western States, under charge of Mr. N. H. Darton.

The information contained in this paper is believed to be of value as a help to the understanding of the underground waters of that portion of the country.

Very respectfully, F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

GEOLOGY AND WATER RESOURCES OF A PORTION OF EAST-CENTRAL WASHINGTON.

By Frank C. Calkins.

INTRODUCTION.

During the fall of 1902 the writer, acting under instructions from Mr. F. H. Newell, chief engineer, United States Geological Survey, made an examination of the water resources of a portion of east-central Washington. The location and extent of the district investigated are shown on the index map, fig. 1.

Fig. 1.—Index map, showing location and extent of district investigated.

The objects of the investigation were determined by the natural conditions of the region. The climate of central Washington is arid, and a large portion of the district here especially considered is almost without surface streams available for the uses of mankind. Surface wells capable of supplying perennially even the modest requirements of domestic use can be sunk only in places where conditions are locally favorable. Springs once formed the only source of water for

a large area, but they are so widely scattered and often so difficult of access that great labor is sometimes involved in hauling a supply from them. Deep wells, now fairly numerous and rapidly increasing in number, are coming to be considered the most satisfactory sources of water. To determine to what extent the supply from these wells may be increased, and to find whether there is hope of obtaining artesian flows in any portion of the region, were the prime objects of the writer's expedition.

Geologic reconnaissance was carried on at the same time, as a knowledge of the character of the rocks and of their geologic structure is necessary to an intelligent opinion in regard to the possibility of obtaining underground water. A sketch of the geology of the region will, therefore, be incorporated in this report. It is limited on the one hand by the economic purposes which it is meant to serve and by the fact that it is intended primarily for nonscientific readers, and on the other by the hasty character of the work and the lack of a good topographic base, which made impossible a complete geologic survey of the region. The routes indicated on Pl. I show the ground covered and will enable the reader to judge to what extent the opinions expressed are based on actual observation.

Field work was carried on during the four weeks beginning October 6, 1902. The equipment consisted of a spring wagon and team, a saddle horse, used in occasional excursions from the main routes, and a light camp outfit. Mr. D. F. McDonald, a student at the University of Washington, was engaged as teamster, and his intelligent interest in the work enabled him to assist materially in the collection of data.

Mention should be made here of geologic and hydrographic work previously done in this region and in neighboring areas where conditions are similar. Among the earliest scientific explorations in the region whose results have been published were those of Thomas W. Symons, who, in the fall of 1881, explored the Columbia from Grand Rapids to the mouth of Snake River. His report [a] includes a description of the Great Plains of the Columbia and a sketch of the geologic history of the region. The most extensive and important work in the Columbia Plains has been done by Prof. Israel C. Russell, the results of whose investigations in central Washington,[b] southeastern Washington,[c] and northwestern Idaho [d] have appeared in publications of the United States Geological Survey.

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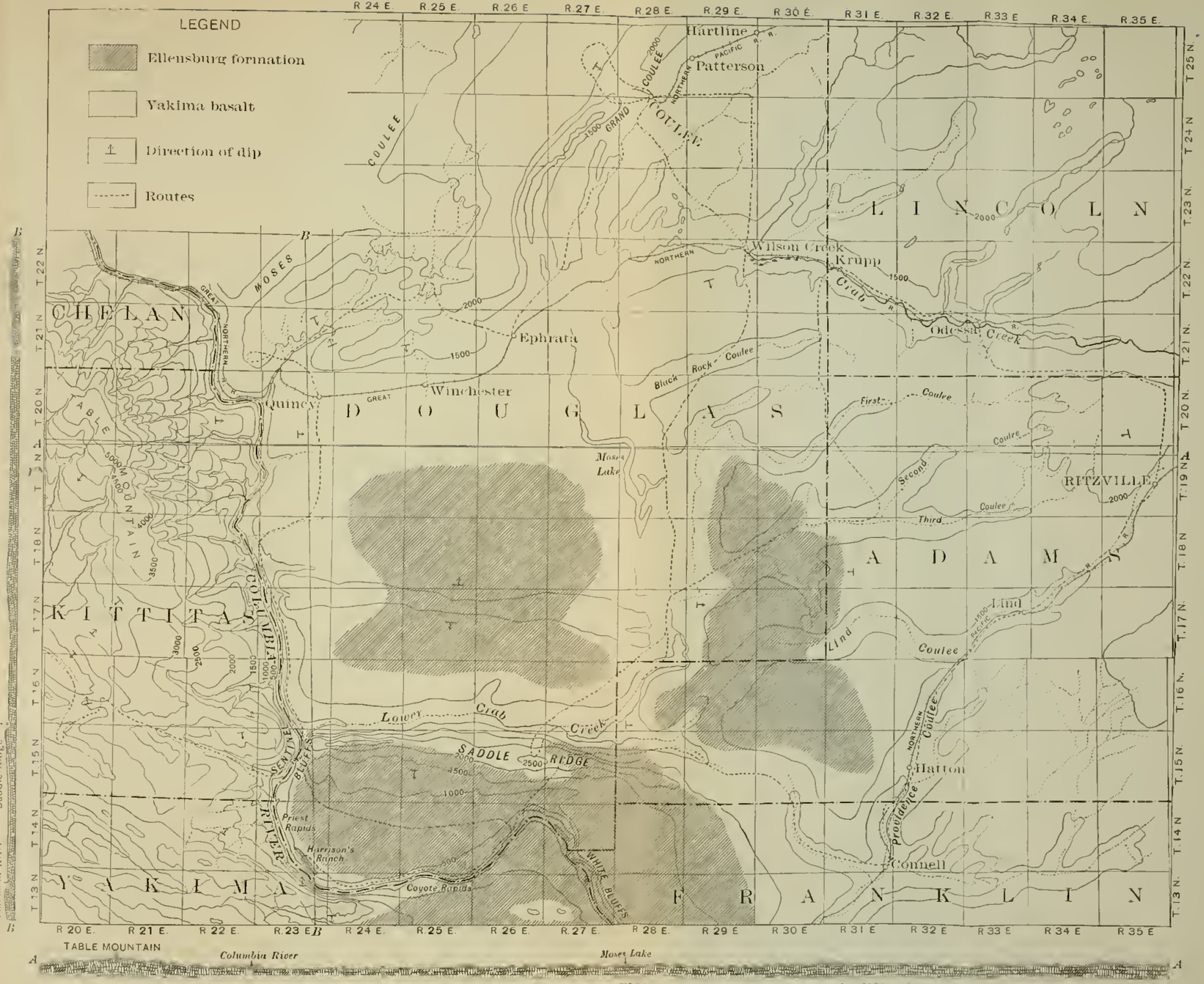
[a] Report of an examination of the upper Columbia River: Forty-seventh Cong., 1st sess., S. Doc. No. 186, 1882.

[b] Russell, I. C., Geologic reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893.

[c] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897.

[d] Russell, I. C., Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Papers Nos. 53 and 54, U. S. Geol. Survey, 1901.



GEOLOGIC SKETCH MAP AND SECTIONS OF A PORTION OF THE COLUMBIA PLAINS, WASHINGTON

TOPOGRAPHY COMPILED FROM U. S. LAND OFFICE PLATS, NORTHERN TRANSCONTINENTAL SURVEY, AND FIELD OBSERVATIONS BY F. C. CALKINS

GEOLOGY BY F. C. CALKINS

1904

Scale

5 0 5 10 15 20 25 miles

Contour interval 500 feet

Datum is mean sea level

Professor Russell's first work in the region was a reconnaissance in 1893, which embraced a large area in central Washington, including the greater part of the district considered in the present report. The conclusions in regard to certain geologic problems reached by the writer after a more thorough examination of the ground differ in some particulars from those of Professor Russell, but they can not claim the authority of final solutions, which must depend on more detailed studies. It is a pleasure, however, to acknowledge indebtedness to Professor Russell for many helpful suggestions contained in his reports.

The water resources of a portion of Yakima County were studied in 1900 by Mr. George Otis Smith.[a] His report is of especial interest because it describes the most successful artesian basin in the State and because his data were based largely on detailed areal work in the Ellensburg quadrangle. The Ellensburg folio,[b] which has recently been published, affords a detailed description of a region where the geologic conditions are similar to those of a part of the area described in the following pages.

The writer's acknowledgments are due to Mr. F. H. Newell and to Mr. George Otis Smith for suggestions and criticisms in regard to the preparation of this report. For assistance in the collection of well data he is indebted to a great number of drillers, ranchers, and others, to mention all of whom by name would require too much space, but to whom he expresses thanks collectively. He would, however, express especial obligations to Mr. Ralph Kauffman, of Ellensburg, who furnished a large part of the information concerning the water resources of Kittitas Valley.

GEOGRAPHY.

TOPOGRAPHY.

MAIN TOPOGRAPHIC DIVISIONS OF EASTERN WASHINGTON.

The most important topographic feature of Washington is the Cascade Range. This noble chain of mountains, beginning in northern California, extends north through Oregon and Washington, but in the neighborhood of the forty-ninth parallel it loses its mountainous elevation and ruggedness and merges into a deeply dissected but distinctly lower plateau. The average elevation of the Cascade summits is between 6,000 and 7,000 feet, and though comparatively few peaks rise above the latter height, a large number are more than 6,000 feet high. A few great extinct volcanoes, such as the well-known cones of Rainier, Adams, and St. Helens, covered with eternal snows, tower to double the height of the rest.

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Wash.: Water-Sup. and Irr. Paper No. 55, U. S. Geol. Survey, 1901.

[b] Ellensburg quadrangle: Geologic Atlas U. S., folio 86, U. S. Geol. Survey, 1903.

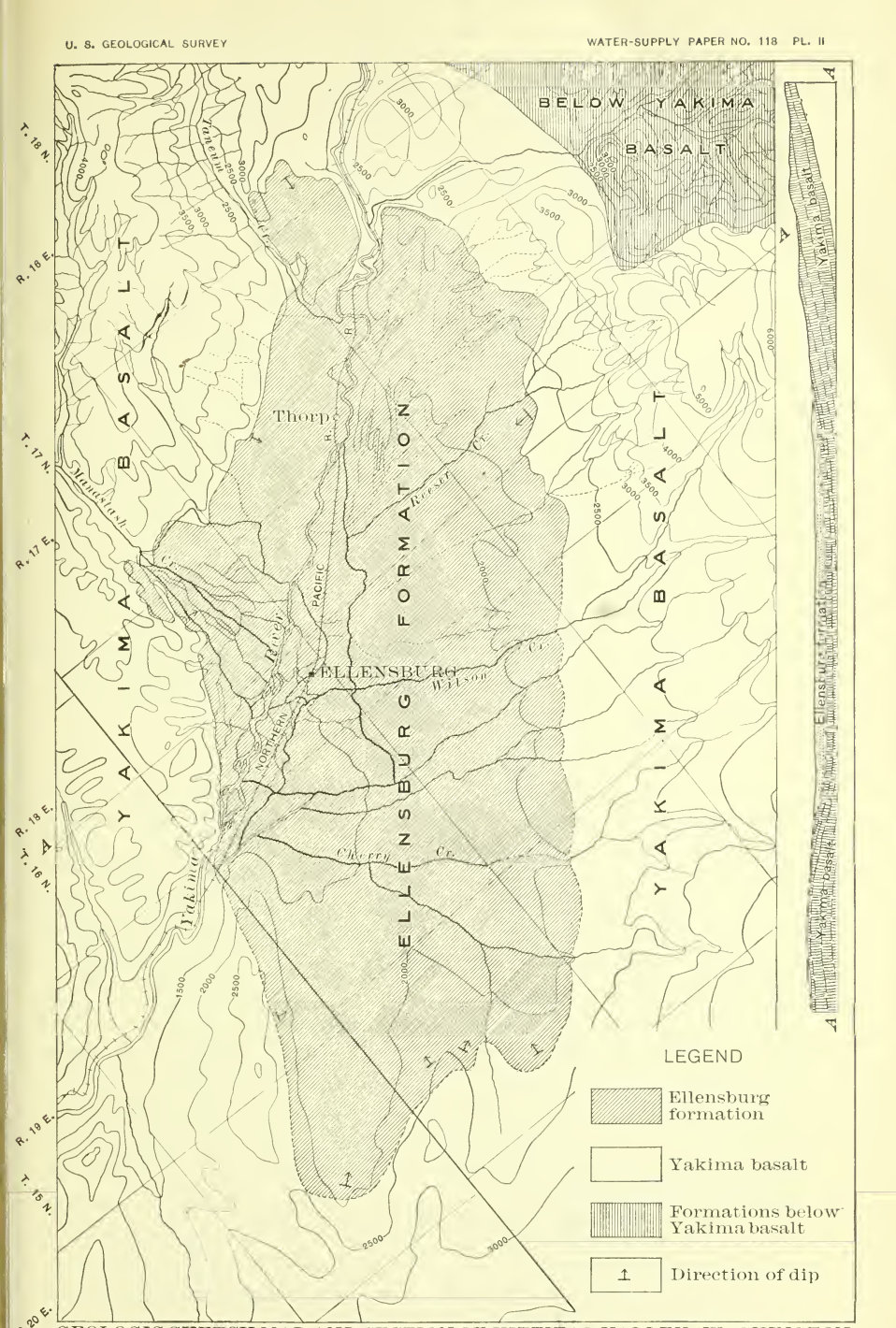
The region east of the Cascade Mountains, in which the area considered in this report is embraced, lies for the most part in that broad topographic province known as the Great Plains of the Columbia. This province may be roughly defined as follows: On the south and southeast its boundary is somewhat irregularly marked by the Blue Mountains of Oregon and Idaho, on the east by the Bitterroot and Cœur d'Alène ranges, on the north by a mountainous though not extremely rugged region comprising the Okanogan highlands and the Colville Mountains, and on the west by the Cascade Mountains, which merge into these highlands.

The extensive area thus outlined is by no means a plain in the strict sense of the word; between its lowest and highest points there is a difference in altitude of 4,000 feet. It includes great plateau-like areas in its eastern and northern portions and broad stretches of low-lying sandy waste along the Columbia in southern Washington and northern Oregon. The level expanses are broken, moreover, by hills and ridges, usually of rather gently rounded profile, and the high plateau-like portions are trenched by streams that have formed magnificent steep-walled canyons. But to the traveler upon the broad stretches between the streams the canyons are not visible until he reaches the brink, and the hills and ridges, not rising in general to great heights, are of little importance in comparison with the vast intermediate areas, level or but gently sloping. Thus the inequalities of the surface, while relieving the monotony of the landscape, do not determine its character, nor make its designation as a great plain seem inappropriate to one familiar with the region.

As the western border of the Columbia Plains crosses the area with which this report is especially concerned it will be necessary to make some further statement in regard to its character and its relations to the Cascade Mountains.

The boundary between the Cascade Mountains and the plains varies in sharpness of definition. North of Wenatchee the division is very accurately marked by Columbia River. West of the profound canyon of this river the country is rugged and thoroughly dissected by streams that are generally separated by sharp, or at least narrow, divides. On the east the rim of the canyon is the edge of a plateau standing about 2,000 feet above the river, and although Badger Mountain rises rather prominently above its general level, and its border is notched by canyons tributary to the Columbia, it has the general topographic character of the Columbia Plains.

South from Wenatchee to Sentinel Bluffs the plains are overlooked on the west by Table Mountain, which rises with a somewhat gentle slope from the brink of the river gorge to a broad summit over 5,000 feet above the level of the sea. South of Table Mountain, however, the boundary between the mountains and the plains becomes less



GEOLOGIC SKETCH MAP AND SECTION OF KITTITAS VALLEY, WASHINGTON

TOPOGRAPHY BY U. S. GEOLOGICAL SURVEY AND NORTHERN TRANSCONTINENTAL SURVEY
GEOLOGY COMPILED FROM U. S. GEOLOGICAL SURVEY SHEETS AND FIELD OBSERVATIONS
BY F. C. CALKINS
1904

Scale

2 0 2 4 6 8 10 miles

Contour interval 500 feet

definite, and there intervenes a region intermediate, not only in position but in topographic character, between the two great provinces in their typical aspects.

This border region is characterized by the presence of many well-defined ridges, whose trend varies from east-west to northwest-southwest, and whose even crests rise gently toward the west and merge with the Cascade Mountains proper, while to the east they gradually sink and are lost on the surface of the plains. Between these foothill ridges there are broad valleys which, by the aid of irrigation, have become the richest farming lands of eastern Washington: the aggregate area of these valleys, however, is barely equal to that of the distinctly hilly lands. To a traveler in the valleys the landscape presents an aspect very similar to that of the Columbia Plains, the resemblance being heightened by the fact that the character of the natural vegetation is similar in the two regions. The hills in the landscape, however, give it a certain degree of contrast with the more monotonous scenery of the plains. This borderland between the plains and the mountains, therefore, while not very distinctly marked off from either, is sufficiently well characterized to deserve recognition as a topographic province. It might appropriately be called the foothill region.

TOPOGRAPHIC DETAILS.

KITTITAS VALLEY.

The region considered in this report includes a portion of the foothill region, but lies mainly in the Columbia Plains.

Kittitas Valley (see Pl. II), which forms the westernmost portion of the area, is the northernmost of the large foothill valleys. The broad floor of this basin-like depression contains an immense area of fertile farm land. Its configuration is favorable to irrigation from Yakima River and from its numerous small tributaries that flow from the mountains west and north, for there is everywhere a gentle slope toward the principal stream. Yakima River, however, does not flow through the valley from end to end, but only traverses its western portion diagonally and makes an abrupt exit through a profound gorge. The southeastern continuation of the basin is without perennial streams, and since it has a somewhat steeper gradient than the western portion, a large part of it can not be irrigated from the highest ditch now taking water from the river.

The flat lands of Kittitas Valley are separated by a considerable stretch of hills from the Columbia Plains.

THE DESERT.

That portion of the plains lying just east of the Columbia has a desolate, almost desert-like aspect, and will for the sake of brevity

be referred to as "the desert." The greater portion of it is nearly level, but its monotony is relieved by two east-west ridges, the most prominent of which is known as Saddle Mountain. This straight and simple ridge extends to a point about 40 miles east of the river, where it sinks gradually to the level of the plain. It is, in fact, an offshoot from the larger Table Mountain uplift, from which it has been cut away by the Columbia. The basalt cliffs known as Sentinel Bluffs, forming the portals of the gate which the river has made through the ridge, are among the grandest scenic features of the region. Saddle Mountain has a fairly gentle southern slope, but its northern face is strikingly abrupt, being for some miles east of the river a precipitous cliff more than a thousand feet high. Farther to the east this cliff gives way to a rather steep slope.

The surface of the desert is covered with a dry sandy soil, which is constantly shifted by the winds, although its motion is somewhat retarded by a scanty growth of shrubs and grass. The character of the soil and climate and the absence of surface water are conditions that have prevented attempts at cultivation, except along Columbia River and Crab Creek, though the northern border of the district is dotted with the cabins of a few homesteaders. The greater portion of the desert is given over to grazing and is without human habitation.

THE WHEAT LANDS.

Embracing the desert-like area on the north and east is the more elevated portion of the Great Plains of the Columbia, which extend northward into the so-called Big Bend of the Columbia and eastward into Idaho. The topographic character of the part south of upper Crab Creek is that of a plateau dissected by canyons. North of Crab Creek there is a ridge, whose cross profile is that of a broad, flat arch forming the south side of a valley with gently sloping sides. The two last-mentioned features are terminated to the west by the Grand Coulee, beyond which rises an elevation, plateau-like in character, but considerably ravined and with no very broad level areas.

These plateau-like portions of the Columbia Plains are fitted by natural conditions to wheat growing, and have a considerable and an increasing farming population. They will be referred to generally in the following pages as the "wheat lands."

DRAINAGE.

Columbia River.—The master stream of the region is the Columbia. Despite its great volume, this river contributes little to the economic resources of east-central Washington. It has several rapids in its course through the region, among them being Priest Rapids, which can not be ascended by steamers except with great danger and

difficulty. These rapids extend for about 7 miles and consist of 7 "ripples;" at the foot of the last one the river is deflected by a ridge having a bold cliff for its northern face, along which it flows for several miles. The fatal obstacle to the use of the Columbia waters for irrigation lies in the fact that the stream flows in a canyon with fairly abrupt walls, sunk from 300 to 1,000 feet below the broad, flat stretches to the east, and that its gradient, though fairly high considering the volume of its flow, is much lower than that of the rivers in the foothill region, so extensively used for irrigation.

Crab Creek.—The large area of the Columbia Plains embraced in the great sweep of the river, bounded on the north and west by the Columbia, on the south by Snake River, and on the east by the one hundred and eighteenth meridian, has only very insignificant surface streams, the only one that maintains a perennial flow along the greater portion of its channel being Crab Creek, which rises in the vicinity of Davenport, Wash., at an elevation of about 2,500 feet. Its total length, neglecting minor curves and including the lakes in its course and the stretches where it flows beneath the alluvium in the bottom of its canyon, is about 250 miles, about the same as that of Yakima River. Its course through this region is readily divisible into three parts. The first and longest of these, in which the general direction of the stream is nearly from east to west, may be designated upper Crab Creek. The surface flow is perennial along the greater part of this stretch, though at the time of the writer's visit the channel was dry from an unknown distance above Odessa to a point about 3 miles below, where the stream emerges from the gravels in considerable volume. It sinks again below Wilson Creek, to rise near the head of Moses Lake, which probably owes its existence to the formation of a range of sand dunes across the ancient channel of the creek. The dam thus formed, however, is a leaky one, and the waters seep through, to gather below, forming a stream perhaps slightly diminished from its former volume by evaporation in the lake. This southward-flowing portion of the stream may be designated middle Crab Creek. About 15 miles below the lake the stream again takes a westerly direction, flowing in a broad-bottomed, steep-walled canyon. At some point near the middle of this lower course Crab Creek sinks finally, and delivers no surface water to the Columbia at the mouth of its canyon. This west-flowing section of the stream may be designated lower Crab Creek.

Coulees.—Crab Creek has only a few branches that contribute to its surface flow throughout the year and a few more that flow during the rainy season, but it has a great number of tributary canyons which are perfectly dry except at periods of unusually heavy rainfall. Many of these are scores of miles in length and of corresponding width and

depth. These canyons, dry or containing only small streams disproportionate to their size, are known as coulees. They have all the topographic characters of stream-carved valleys, but it is evident that they could not have been formed by stream erosion under present conditions. Their origin must be referred to a prehistoric period in which the region had an abundant rainfall and was well watered by surface streams. These branching systems of dry canyons represent ancient river systems.

The most important of the branches of the ancient Crab Creek system, except Grand Coulee, whose peculiar history separates it from the others, is Lind Coulee, in which the Northern Pacific Railway runs from Providence to Ritzville.

Providence Coulee, in which Hatton, Scott, and Connell are situated, is now devoid of flowing water, though it once formed the trunk of a river system almost as considerable as that for which Crab Creek is the master stream.

Of all the abandoned canyons of the Columbia Plains, however, the greatest and most remarkable is Grand Coulee. Not only does it possess many features of scenic grandeur, but its geologic history is of the highest interest. This great chasm was carved by Columbia River at a time when its profound gorge was dammed by a great ice lobe that came down the valley of the Okanogan and pushed southward some 30 miles across the plateau south of the master stream. The waters of the Columbia, deflected by the great glacier, flowed along its eastern face, and, continuing southward in what is now the bed of Crab Creek, regained their proper channel just above Sentinel Bluffs.

Opening from the canyon of the Columbia near the northwest corner of Lincoln County, the Grand Coulee extends in a southwesterly direction for over 30 miles. Throughout the greater portion of this distance it is a wide, flat-bottomed canyon, walled by cliffs, but a little south of its middle point its western wall subsides and it is joined by a broad valley with gently sloping sides. Opposite the mouth of this valley a plateau rises nearly a thousand feet above the bottom of the coulee, but the ascent to this upland is made on a moderate slope unbroken by cliffs. This break in the walls of the chasm, constituting the only point where the Grand Coulee proper can be crossed by a wagon, has determined the location of the small town known as Coulee City. Above this middle pass the coulee bottom, partly covered by alkaline lakes and playas, is about 1½ miles wide, with basalt cliffs which rise on either side to a height of about 400 feet. Two miles below the town the bottom of the canyon abruptly drops, and two amphitheaters, separated by a narrow point and walled by vertical cliffs 400 feet in height, mark the place where the Columbia once poured in a mighty cataract.

The gorge extends southward 15 miles farther. The eastern wall of this lower section does not rise much higher than the level of Coulee City, but its western side maintains a commanding elevation and forms a frowning escarpment visible for many leagues to the south and east. The coulee finally opens out in the northeastern portion of the desert upon a gravel plain, the surface being higher than that of Soap Lake, the southernmost of the chain that lies in the deep chasm. Beneath the mantle of surface material, however, the rocky channel probably persists, and is continued in the depression occupied by Moses Lake and Crab Creek.

Lakes.—Lakes, generally shallow and of small extent, are very numerous in the northern portion of the region. They are invariably situated in coulees, their basins having been formed by the erosion of former streams or dammed by wind-blown materials. They are, therefore, usually elongated in form and separated by stretches of dry or meadowy land; often they are disposed in chains. The most important series in this region is that which lies in the bottom of the Grand Coulee. In this chain we may include Moses Lake, the largest sheet of water in the Columbia Plains.

The majority of the lakes in this arid region have no outlets, while others overflow only in the rainy season. As a consequence, the small amounts of salts contained in all surface waters are concentrated in the lake basins by evaporation, and a majority of the lakes are more or less alkaline, Moses Lake containing about 0.32 gram of total solids per liter of water.[a]

The lakes in the lower section of the Grand Coulee are successively higher from south to north, and the northern lakes occasionally overflow to the south at seasons of high water. It follows that, while the water of the northernmost of these lakes is comparatively fresh and palatable, the waters of the others become successively more alkaline to the south. Soap Lake, the most southerly, is extremely alkaline; its waters when they lap against the shores on windy days are beaten into great masses of white foam like soap suds. The alkalinity of the lake is further shown by the soapy feeling observed on rubbing the hands in its water and by its bitter taste, so strong and disagreeable that it is refused by a thirsty horse accustomed to more palatable water. The cattle of the neighborhood, however, constrained by necessity, have overcome this natural repugnance and the lake is a drinking place for a large number of them.

Soap Lake contains 28 parts in 1,000 of matter in solution, consisting essentially of carbonates, sulphates, chlorides, and bicarbonate of soda.[b]

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[a] Ann. Rept. Geol. Survey of Washington, vol. 1, 1901, p. 294. [b] Ibid., p. 295.

Sulphur Lake, in Washtucna Coulee, is another pond in which the water is an extremely concentrated alkaline solution.

In this connection should be mentioned the numerous "alkali flats" or playas, which are ponds during a portion of the year, but become dry every summer, and which have their supply of salts annually increased by the amount held in solution by the waters that flow into them during the rainy season.

A typical coulee, containing small lakes, is shown on Pl. III, A.

CLIMATE.

The most characteristic climatic features of eastern Washington are due to the fact that the region is separated from the ocean by a broad belt of fairly high mountains. The great influence of the Cascade Range is rendered manifest by the sharp contrast that obtains between the climates of eastern and western Washington. The region on the seaward side of these mountains has a climate that is remarkably mild, considering the rather high northern latitude, and that is without extremes of heat or cold. The most characteristic feature, however, is its extreme humidity. The eastern part of the State, on the contrary, being removed from the tempering influence of the ocean and the warm Japan Current, which flows along the north Pacific coast, has the wide range of temperature that is characteristic of the climate of interior regions. The winds of the Pacific, which supply the abundant rainfall of the Sound country, can not cross the broad Cascade Range without losing the greater portion of their moisture by condensation in the form of rain or snow, and the climate of eastern Washington is therefore as decidedly arid as that of western Washington is humid.

The average yearly rainfall in Kittitas Valley, as deduced from Weather Bureau statistics covering many years, is approximately 8 inches. For other localities in the area with which we are directly concerned there are only the most fragmentary records. At Lind, in the wheat lands, the observations for 1898 and 1899 show a total for each year of about 12 inches. Incomplete records at Ritzville during the same years apparently indicate an annual average about equal to or slightly less than that of Ellensburg. At Coulee City the scanty data indicate an annual rainfall not far different from that of Ritzville. At Connell, in the southeast quarter of the area considered, the precipitation in 1900 was 2.29 inches for all of the year except April and November; in 1899, 2.24 for all except January, February, and March. These figures indicate that the mean precipitation at that locality is extremely low, probably not above 5 inches per annum. Although figures are lacking for what has been termed the desert, its general aspect indicates that its annual rainfall probably does not average more than that of the vicinity of Connell.

A. TYPICAL COULEE SOUTH OF COULEE CITY.

B. COLUMNAR PARTING IN BASALT, UMPTANUM VALLEY.

The seasonal distribution of the precipitation is very characteristic; as in all the far West, there is a wet season and a dry season. By far the greater portion of the annual supply of rain and snow falls between October 1 and May 31. The precipitation is for the most part in the form of gentle rain, which is generally almost entirely absorbed without considerable loss by run-off. The amount of snowfall in winter is often fairly large, however, and the drifts are often sufficiently deep on the hills to obstruct travel from Kittitas Valley to the Columbia.

The mean annual temperature at Ellensburg is approximately 48°. For localities in that portion of the area considered which lies in the Columbia Plains very scanty records are available. In 1899, when the annual average for Ellensburg was 46.5°, that for Lind was 50.2°. It may be safely asserted that the average temperature for the eastern part of the area is slightly above that for Kittitas Valley, and probably not far from 50°. The range of temperature, as mentioned before, is high, the greatest variation noted being in the Weather Bureau record for Lind during 1899, when the maximum was 112° and the minimum —33°. The temperature at Ellensburg, however, generally keeps within the limits +96° and —15°, while in the lower portions of the Columbia Plains both limits are somewhat higher. The figures giving the dates between the last killing frost in spring and the first in autumn are of considerable interest to students of agricultural conditions. The last spring frost usually occurs in the latter part of May, but has been known to be deferred until early in June. The first severe frost of autumn usually falls near October 1, but occurred at Ellensburg on September 9 in the unusually severe year of 1895. The lateness of spring frosts is inimical to the culture of such fruits as peaches, cherries, and apricots.

VEGETATION.

The natural vegetation of central Washington is chiefly influenced in its broad variations by climatic conditions. The only great forested area in the region here considered is on Table Mountain, whose height gives it a much moister and cooler climate than that of most of the region. The Columbia Plains and the comparatively low foothills are almost treeless, though Yakima River and certain small streams are bordered with a more or less considerable growth of trees and shrubbery. The treeless regions are clothed with a scanty vegetation composed of hardy grasses and shrubs, whose general aspect would be familiar to anyone acquainted with the arid regions of the West. In addition to the important influences of climate and water supply, soil conditions cause more local and less conspicuous variations in the flora.

The forest that clothes the top of Table Mountain comprises many species of fir, spruce, pine, and tamarack. In the sparse growth of its lower slopes the prevailing species is the yellow pine. The woody growth that borders the Yakima includes many large trees, mainly cottonwood and alder, with a sprinkling of yellow pine and a dense undergrowth of willows and other shrubbery. East of Kittitas Valley there are few plants worthy to be called trees. The small streams and springs are fringed with a more or less scattered growth of willow, birch, and wild cherry. The Columbia's banks are destitute of trees except for a few small junipers growing on its flood plain.

On the Columbia Plains and the southeastern foothills, almost desert-like in their aspect, the characteristic species are sagebrush and bunch grass, occurring in variable proportions. Sagebrush is moderately plentiful in all the western part of the region exclusive of the forested areas, attaining perhaps its greatest size and abundance in the central portion, near the boundary between the desert and the wheat lands. Eastward it diminishes, growing rather sparsely about Connell, Ritzville, and the other towns along the Northern Pacific Railroad. Bunch grass was seen in greatest luxuriance where the sagebrush is least abundant, but as it had there been protected for some years by fencing, it is difficult to say where it grew thickest before the land was swept by grazing herds.

The local variations of flora, determined by the character of the soils, are of considerable interest. In the sandy western portions of the plains, for example, while the general aspect is similar to that of the typical sagebrush land, the shrubs are mainly of species other than the true sage, and the true bunch grass is replaced by species more adapted to survive in this very dry soil. In the coulee bottoms other peculiar conditions have an equally decided influence on vegetation. The borders of the fresh-water ponds support a growth of tules. The meadow lands are covered with wild grasses, the short stiff-bladed salt grass being characteristic of the more alkaline soil. In soil that is alkaline but dry rye grass and greasewood, or thorny sage, form the principal growth. The character of the vegetation thus affords an index of the agricultural properties of the soil.

GRAZING.

The early settlers found eastern Washington a rich grazing region. The natural growth of nutritious bunch grass was so abundant that winter feeding often could be dispensed with and cattle and horses wintered on the open range, though there was doubtless great hardship and frequent death from cold in the more inclement winters. In the eastern portion, however, there was always the great drawback common to so many of the western ranges, of scanty water supply,

and during the hot months the necessity of keeping within a moderate distance of water prevented the stock from availing themselves of the entire grazing area.

Since the early days, however, the ranges of east Washington have greatly deteriorated. In this, as in most other western grazing regions, the forage plants have been eaten down so constantly that the forces of growth have been unable to compensate for the continual loss, and the evils of overgrazing have conspired with the encroachment of other agricultural industries to cause a decline in the extent and profitableness of the stock business. In consequence of the last-named cause the areas devoted to open grazing have been reduced to include only the lands unfitted by their topography, the nature of their soil, or the insufficiency of their water for the growth of hay, grain, and other crops.

The most important of the areas still devoted to grazing are the hills and the desert.

The rolling hills in the southwest part of the region and the slopes of Table Mountain constitute a large and important stock range. They have few level tracts extensive enough for economical cultivation, and the soil is generally thin and interrupted by patches of barren rock. In a state of nature the hills were abundantly clothed with bunch grass, and still afford excellent pasture where excessive grazing has not occurred. Springs and rivulets, though not abundant, are plentiful enough to render the greater part of the grass available to the stock.

The second great stock range is coextensive with what we have termed the desert, where the sandy character of the soil, combined with great aridity of climate, seems to forbid the hope of dry farming, and where there is no water for irrigation. Watering places are here few and far between. In the northeast quarter the grazing animals resort principally to Moses Lake; farther south, and near the eastern limit of the range, to Skuten Springs; in the central portion of the desert, to lower and middle Crab Creek; and along the south and west edges, for the most part, to Columbia River, although in the northwestern portion, where the stream is bordered by lofty basalt cliffs, they resort in part to springs. The dispersion of drinking places, as an inspection of the map will show, is so great that there are spots that lie many miles from any surface water.

The effects of excessive grazing are first felt in the areas near springs and streams, a fact strikingly evident to every traveler in this desert-like region. Along the borders of the streams there are broad stretches, often many miles across, where the bunch grass has been eaten down to nearly complete extermination. Farther back

from water the grass is much less closely cropped, and there are areas that seem to lie almost untouched from year to year.

There is another way in which the hard conditions of life on the range are forced upon the attention of the traveler. He will soon notice that the plain is traversed by numberless straight, deep-worn trails, and further observation will show that they are arranged in systems, converging toward points on the borders of a stream canyon or of some coulee in whose depths there is a spring or lake. Following a trail in the direction of water, he will find the minor paths gathering together as do the branches of a river system, to unite finally in a broad, well-beaten track that passes down some gully affording a graded route to the drinking place. A thirsty animal at any point in the arid range, by merely falling into the nearest trail and following it to the end, may generally make his way to water by the shortest possible route. A frequent and impressive sight is that of a band of horses on the way to a drinking place, following a trail in single file and moving at a swinging trot or easy lope in order to consume a minimum of time in the necessary quest for the refreshing element. In the dry season this journey must be made daily, but in the other months, when the demands of nature are less and are partly supplied by snow and the rain absorbed by the dry grass, the stock may abstain from drinking for several days at a time.

Since the horse can cover more ground and can afford the time to make longer journeys to water, the excessive restriction of the range has been more prejudicial to cattle than to horses, and horses have therefore become much more numerous than cattle upon the open range.

Two minor classes of range land remain to be noticed. The first comprises the slopes bordering the coulees of the wheat lands. Broken by terraces and by outcrops of basalt, they are unsuited for grain culture, but bear a considerable growth of bunch grass. In the aggregate these lands constitute a large area adapted for grazing, and one that probably never can be available for any other use.

The second class comprises certain narrow strips lying along rivers and lakes and watered by their underflow or seepage. The gravelly flood plain of the Columbia supports in places a scanty growth of lupine and other weeds that are eaten by cattle. The horses prefer to range back where the forage, though less palatable than this verdant growth, can be gathered more rapidly, and thus the green fodder is left to the sluggish cattle. More important, however, are the natural meadows that border Crab Creek and some of its tributaries, with certain of the desert lakes. These meadows are covered with abundant grass, and the generous growth has led to their being appropriated, fenced off, and used for pasturing and hay growing.

AGRICULTURE.

GENERAL STATEMENT.

In the early days of settlement the sole agricultural pursuit of eastern Washington was grazing on the open range. Owing, however, to natural laws of development, this industry has been displaced to a large extent by others which involve the tilling of the soil, and which, while yielding immensely greater returns, acre for acre, than grazing, require less capital than is required for the inception of a profitable stock-raising business. The directions of this later development have differed in Kittitas Valley and on the Columbia Plains. This fact, while due in part to differences in soil and climate, depends in a far higher degree on the conditions of water supply. Kittitas Valley is an irrigated region, while on by far the greater part of the Columbia Plains dry farming alone is practicable. While the discussion of open grazing, therefore, has been made general for the entire region, the other agricultural industries must be described separately for Kittitas Valley and the plains.

THE COLUMBIA PLAINS.

NATURAL CONDITIONS.

The cultivated portion of the Columbia Plains may be classified as plateau lands, meadow lands, and bench lands.

By far the most important in extent are the plateau lands, comprising the broad, level upland areas. The important natural conditions influencing agriculture upon the plateaus are (1) an arid climate, (2) absence of surface water for irrigation, and (3) a soil easily tilled, fertile, and peculiarly adapted to retaining and utilizing the scanty precipitation. The soil of the plateau lands is shown by chemical analysis to abound in the elements necessary to support plant life. Its peculiar virtues, however, are probably due less to its chemical than to its physical properties, its fine open texture rendering the plant food readily available and its friable character and freedom from stones making it very easy to till. Probably most important of all, however, is its behavior toward water. On the one hand, it is so porous that rain or melted snow is quickly absorbed by it, so that a smaller proportion is lost by run-off or by evaporation from puddles than would be lost if it were more clayey and impervious, and, on the other hand, it is not loose enough to allow the water to sink rapidly and become unavailable, as it does in a deep sandy soil. The spaces between the particles of the fine loam are so small that the water is held in them by adhesion or capillary attraction, and yields to the force of gravity only slowly and to a comparatively small extent. Therefore a large proportion of the slight precipitation is kept sufficiently near the surface to be used by the growing

wheat, and successful grain culture is possible with a rainfall that would be insufficient in a soil of less advantageous physical constitution. Dry farming of grain is the industry found most profitable under these conditions, and absorbs by far the greatest part of the energies of the farming population in this district, as well as in eastern Washington generally.

Far less in area than the grain lands are the meadows of Crab Creek, Grand Coulee, and Harrison Springs, characterized by heavy, moist, generally alkaline soils, and chiefly devoted to hay and pasture.

The bench lands comprise a comparatively small area on the terraces of Columbia River, where the sandy alluvial soil is irrigated with river water and produces a variety of crops.

DEVELOPMENT.

Grain culture.—The invasion of the land by the wheat industry has proceeded from the northeast. The settlement of the district about Ritzville, the thriving county seat of Adams County, dates back nearly a score of years, and the well-tilled farms, the numerous small but flourishing orchards, and the substantial farm buildings give this vicinity a gratifying aspect of prosperity. The villages on the Northern Pacific Railroad southwest of Ritzville and along the Great Northern are lively and growing, but glaringly new, and the hastily constructed, often unpainted frame house is the prevailing architectural type. The whole aspect of the country also speaks of its recent settlement. In the vicinity of Connell a large proportion of the wheat land has been broken in the past year, and many sections, protected from grazing by fences, still bear an abundant growth of bunch grass.

To the west also the frontier of the wheat belt is being pushed to the border of the desert. The land is dotted with the board shanties of homesteaders and with newly plowed squares that break the surface of the virgin ground. The clearing away of the strong and abundant sagebrush of this district preliminary to the first sowing is no small task, and many entire families are to be seen engaged in uprooting the shrubs, collecting them in wagons, and feeding them to blazing bonfires. The wholesale destruction of the brush is rather to be deplored, for the roots and lower stalks are used as fuel in many homes, and, while far from ideal for this purpose, must be of considerable value in a region where wood is so difficult to obtain.

The earlier settlement of the northeastern part of this region is not due to chance alone, but in part to better natural conditions, the greater rainfall giving this section a natural advantage over the country to the southwest. The appearance of the stubble after the fall harvest, as well as general report, indicates that it is superior in natural productiveness to the more arid districts. Part of the

apparent superiority is doubtless due to long cultivation of the land, for the best results are not obtained until about three years after the first breaking, when the roots of the sagebrush and bunch grass are quite decomposed. But after making all allowances it still seems unreasonable to expect as good returns in the recently settled districts to the south and west as from the older land, where crops may suffer heavily in years of especially light rainfall.

Exact data concerning the yield of wheat are difficult to obtain, but the general run of crops appears to be from 16 to 25 bushels per acre. Extremely large yields are not necessary for profitable culture, for the land is low in price and so easily worked that the cost of cultivation is much less than in heavier lands. It seems necessary, however, to work a considerable holding, and the ranches are probably in a majority of cases a section or more in area. The advantages of close settlement and small farms will perhaps never be attained.

Forage growing.—An important adjunct to the grazing industry is the culture of hay for winter feeding. There are numerous farms along upper and middle Crab Creek where hay is gathered from the meadows, the crop being stored in large stacks and the mown fields used as pastures for some time after harvest. The greater portion of this hay is fed on the ranches, for while a minor quantity is hauled to villages in the wheat lands it can hardly compete successfully with wheat hay and hay imported from the irrigated districts to the west. Unfortunately, the strongly alkaline character of the soil is fatal to the better forage plants, and the crop is of wild hay, very inferior in nutrient qualities to timothy, clover, or alfalfa. One hay ranch, perhaps the most important seen during this reconnaissance, is located on spring-watered land at the foot of Priest Rapids. At this locality the excessive moisture of the soil is prejudicial to domesticated grasses, though they have gradually been introduced to a slight extent, and the quality of the crop is thereby improved.

Horticulture.—Though horticulture in this portion of the State is not an important industry, orchards for supplying the needs of a household are very generally to be found on the older ranches, and larger ones are fairly numerous in the neighborhood of Ritzville. Two were seen on Columbia River, one irrigated by a water wheel and another by a small ditch from a neighboring canyon. So far as known, no shipments of fruit are made to distant parts of the State.

The natural conditions in the wheat country are unfavorable to fruit culture in many ways. The late frosts in spring, as experience has shown, are often fatal to the growth of peaches where they have been tried. The hardier apples often attain good size and quality, especially upon high ground, and prune trees are said to yield good

crops. Excellent pears are grown on the McMannamon ranch on middle Crab Creek, where the alkali of the soil is injurious to most other fruit trees. In the land bordering Columbia River there seems reason to hope that fruits may be grown with much success if extensive irrigation can be provided, for at Wenatchee, where temperature conditions are probably very similar, fruit culture is a flourishing industry.

Small fruits are said to thrive where their culture has been attempted, notably on the plateau west of Grand Coulee. Domestic vegetable gardens, with cabbage, corn, and other hardy plants, add to the comfort and convenience of many thrifty ranchers, but generally do not present a flourishing appearance.

Except at the two localities on Columbia River already mentioned, practically no fruits are irrigated in this region. Vegetables are sometimes watered by a small stream from the farm well, but no extensive, systematically irrigated gardens exist. If irrigation were possible there is no doubt that the quality and amount of fruit and vegetables raised in this region might be greatly increased. The extent to which irrigation may be practicable will be discussed later.

KITTITAS VALLEY.

NATURAL CONDITIONS.

The broad floor of Kittitas Valley presents a large area of alluvial soil of great natural fertility. The annual rainfall is too low to support agriculture in itself, but this deficiency is more than overcome by the conditions that have made it possible to irrigate a large portion of the land from mountain streams. The rather low mean temperature and the lateness of spring frosts is disadvantageous and makes horticulture less successful than in the Yakima region, where conditions are otherwise similar. The character of the agricultural industries of Kittitas Valley has been determined by the conditions thus briefly outlined. They may be classified as follows: (1) Growing of forage; (2) dairying; (3) grain culture, and (4) horticulture.

Forage growing.—In the winter feeding of sheep, cattle, and horses that range the neighboring hills and mountains a large amount of forage is consumed on the valley farms. But as the irrigated lands are eminently suited to the growing of hay and the warm dry months of summer enable the farmer to cure it thoroughly with small risk of injury by rain, a large surplus over that consumed locally is raised, the different varieties of hay, mainly timothy, clover, and alfalfa, constituting one of the most important crops of the region. It is baled and exported in large quantities and finds ready sale at

prices considerably higher than those obtained for the forage grown in the more humid region west of the Cascades.

Dairying.—The abundance of the best fodder and the excellent pasture afforded by hay fields in the intervals of cropping are conditions favorable for milch cattle, and dairying is an industry of considerable importance. While no large farms are entirely devoted to it, the great majority of ranchers produce small quantities of milk, which is collected daily by the several creamery companies and worked into excellent butter on a large scale. There are six creameries in the county, which is among the most important dairying counties of the State.

Grain culture.—Grain, including wheat, barley, and oats, in order of importance as named, is a crop of considerable magnitude, the greater part being grown on the marginal portions of the valley, where there is not sufficient water for the proper irrigation of hay.

Horticulture.—There are probably no ranches in Kittitas Valley with horticulture for their principal dependence, but nearly every thriving farm has its garden and orchard to supply domestic needs. Nearly all vegetables do well under irrigation, and considerable quantities of small fruits and vegetables are exported. The climate, as before noted, is unfavorable to most orchard fruits. Apples are the only ones grown in sufficient quantity for export; these are of excellent appearance and flavor, and generally freer from worms and other defects than the fruit of western Washington.

GEOLOGY.

GENERAL STATEMENT.

The area considered in this report lies wholly within the vast territory which, in Miocene time, was inundated by great floods of basaltic lava. Throughout the greater part of the region the basalt lies not far beneath the surface. Though for the most part covered with soil in the level upland stretches and gentle slopes, it is exposed in the walls of nearly every coulee or canyon. From this rock are carved the imposing but somber cliffs of the Grand Coulee, the gorge of the Columbia at the foot of Table Mountains, and the majestic Sentinel Bluffs. Its depth appears from the fact that nowhere within the limits of this reconnaissance has it been cut through by the streams that have so deeply trenched it.

Upon the basalt, in late Miocene time, there were laid down several hundred feet of sediments belonging to what is known as the Ellensburg formation. While these beds may have been deposited over the greater portion of the area considered, they have yielded with comparative readiness to erosion, and now occupy but a fraction of the land surface. In the White Bluffs of the Columbia this formation is splendidly exposed.

Since the deposition of the Ellensburg beds the layers of rock, originally horizontal, have been tilted and folded, and the land has been modeled to its present form by the work of water, ice, and wind.

STRATIGRAPHY.

YAKIMA BASALT.[a]

DISTRIBUTION AND VOLUME.

By reason of its vast extent and great volume the basalt of the Columbia basin is one of the most important volcanic formations in the world. Its greatest thickness is not less than 4,000 feet, and its area, including portions of Washington, Oregon, and Idaho, has been estimated at about 250,000 square miles. In Washington and Idaho the area underlain by it includes practically the entire Columbia Plains and that portion of south-central Washington designated the "foothill province," as well as a considerable strip along the southern border of the State, crossing the Cascade Range and extending west to the ocean.

East of the area immediately considered here the Yakima basalt, where its edge is exposed, is underlain by Tertiary sandstones. Just south of Wenatchee the northern face of Saddle Mountain is a lofty and precipitous cliff of basalt, at the foot of which lies a belt of low hills carved from the rather soft sandstones which occupy both sides of the river at Wenatchee, but soon thin out to the north. From a short distance above Wenatchee to the mouth of the Okanogan the boundary of the lava is marked by the Columbia, whose left bank is overlooked by a precipitous wall, with a top or "rim" of basalt, immediately underlain by old crystalline rocks, such as granite, gneiss, and schist; to the north these older rocks are not exposed, the basalt forming the entire wall of the canyon.

Near the Okanogan the boundary again crosses the Columbia, and is, in general, coincident with the southern border of the Okanogan highlands. On the northeast and the east the lava reaches up the lower slopes of the mountains in Idaho, remnants of it being found along the valley of Spokane River, about Cœur d'Alène Lake, and along the lower parts of the rivers flowing into it. Along the entire northern and eastern boundaries the surface upon which the basalt was poured out is supposed to have consisted of ancient, mostly crystalline, rocks. To the south, southeast, and southwest the basalt area extends for considerable distances into Idaho and Oregon, but its delimitation in these directions need not be dicussed here.

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[a] This name was first used by Mr. G. O. Smith in Water-Sup. and Irr. Paper No. 55, and is applied to the Miocene basaltic series of this region. The term "Columbia River lava," as used by Professor Russell, includes Eocene and Pleistocene lavas separated from the Yakima basalt by important sedimentary formations.

ORIGIN.

The origin of a body of lava so vast and widespread is an interesting problem. It is a generally accepted view that the originally molten rock was forced up through great cracks or fissures in the crust of the earth; this theory is based on three kinds of evidence: (1) The volume and extent of the lava floods are so enormous that it is difficult to conceive of their eruption from ordinary craters; (2) the comparative rarity of the fragmental materials known as "tuffs," "breccias," etc., indicates a quiet welling up through fissures without the explosive action characteristic of crater eruptions; (3) the theory has received very positive confirmation of late years by actual observation of the fissures from which these floods came forth, filled with the cooled and hardened basalt and exposed by the erosion of the overlying flows. In the Cascade Mountains there is a great system of dikes in the sandstone beneath the basalt, which has been described by Professor Russell[a] and by Mr. George Otis Smith.[b]

The thousands of feet of basalt in the plains were not poured forth in one great outburst. The series is made up of a great number of layers or flows that can be distinguished in the field by means to be discussed in another section. It is estimated that about twenty such flows have been cut through by the river at Sentinel Bluffs. Each of these layers represents a distinct outpouring of basalt, the eruptions being separated by various intervals of time. In some cases these periods of rest must have endured for centuries, for at certain localities there are beds of soil between the layers on which trees have grown to considerable size, to be charred and buried by later flows. The basalt eruptions, especially in the later stages of their activity, were interrupted by periods in which there were accumulated other materials, consisting of volcanic ashes of a composition different from that of the basalt, and beds of sand, clay, or gravel, laid down in lakes or rivers.

The average thickness of the individual flows in this region is probably between 50 and 100 feet. Their extent, considered separately, must have been enormous, for it is rare to see the edge of a layer thinning out. This fact indicates that the molten rock was in a highly fluid condition and retained its fluidity long enough to spread out for great distances.

In addition to the massive flows that form the greater part of the series there are beds of fragmental volcanic material, such as bombs or smaller angular fragments of lava. Such materials either have been thrown up to great heights and spread out upon the surrounding

[a] Russell, I. C., Preliminary paper on the geology of the Cascade Mountains in northern Washington: Twentieth Ann. Rept. U. S. Geol. Survey, pt. i, 1899, pp. 121–122, pl. xii.

[b] Smith, G. O., Mount Stuart: Geologic Atlas U. S., folio 106, U. S. Geol. Survey, 1904.

country, or, mixed with hot volcanic water, have formed mud flows and run out on the surface in much the same way as true lava. Their formation was perhaps due to the partial choking of fissures by congealed material, and the building of craters where the pent-up subterranean forces found constricted vents. The fragmental materials are not so generally distributed nor so widespread as the massive flows; they are most numerous and thickest in the mountains, while in the Columbia Plains they form but an insignificant proportion of the basalt series.

LITHOLOGIC CHARACTER.

The textural and structural features of the basaltic rocks are of interest not only to the scientist, as throwing light upon the manner in which the lavas were erupted, but to the practical man also, for the deep water of this region is found chiefly in the basalt series. The lithologic characters will therefore be considered somewhat fully.

The texture of the basaltic rock, viewed in small specimens or fragments, shows a considerable range of variation expressive of the different rates at which the lavas cooled. The central portions of thick flows, where cooling has been slow, are often completely crystalline. In thin flows, or near the surfaces of thicker ones, the rock is of finer texture, is generally dull in luster, and does not show, to the unaided eye, the minerals of which it is composed. Where the basalt has been suddenly chilled, especially at the base of a flow, the lava may solidify as a black glass. From the practical standpoint, however, the most important fact in regard to texture is that the basalt is generally fine and compact, with no pores capable of allowing water to pass to any appreciable extent through the solid rock.

The structural characters of lava flows are dependent on conditions attending their eruption and cooling, and may best be described with reference to their origin.

SURFACE FEATURES OF LAVA FLOWS.

Molten lava, as it issues from the earth, is always charged with steam. While the lava remains underground the steam is intimately mixed with the molten rock and is prevented from expanding by the enormous pressure of the overlying crust. When the lava emerges on the surface, however, there is a sudden decrease in pressure, and the steam combined with the lava expands and collects in bubbles, which rise to the surface and burst, giving off the great clouds of vapor that always rise from a moving flow of lava. The solidification of the molten rock generally takes place, however, before the steam has entirely escaped, and the bubbles in the upper portion of the flow become, as it were, frozen, so that the upper surface of a lava flow has generally a vesicular or honeycombed character. It is

by this structure that the upper surface of a flow is best distinguished and the different flows distinguished from one another. The bottom of a sheet sometimes has this vesicularity in a minor degree, owing to the sudden chilling and solidification of that portion before it has freed itself from watery vapor.

Another common surface feature is that produced by the formation of a crust on the top of a flow and its subsequent disruption by the onward movement of the still liquid lava beneath. The rough scoriaceous layer, formed by the fragments of this crust cemented by other molten material, is called a flow breccia. Again, the crust formed upon the advancing front of a lava flow may often be broken and the fragments rolled under and incorporated in the bottom part of the moving sheet of molten material.

CONTRACTION PARTINGS.

After the lava has completely solidified it is still at a temperature enormously higher than that which it must ultimately attain, and a gradual cooling progresses for a considerable time. Cooling, in the case of basalt as of most other substances, brings contraction. This necessarily leads to the formation of joints and small fissures, dividing the rocks into blocks or plates of varying size and regularity, and such contraction partings are of universal occurrence in the basalts of the Columbia basin. The forms into which the lavas are thus divided are multitudinous, but are divisible into a number of classes, each of which will be briefly described.

Columnar jointing, generally perpendicular to the cooling surfaces and therefore most often nearly vertical, is the most universal and striking structural feature of the basalt flows (Pl. III, *B*). The columns vary greatly in size and regularity of form, their diameters ranging from a few inches to 6 feet. They are sometimes so straight, sharp cornered, and clean cut as to simulate the work of human hands. More frequently, however, they exhibit imperfections of form, the sides being warped and not parallel to one another. Cross sections of the most perfect prisms are oftenest pentagonal or hexagonal, but polygons of 4, 7, or 8 sides are also common.

The main vertical columns of the basalt flows are generally subdivided by secondary partings. Most universal is a transverse jointing, dividing each column into sections of varying lengths. An extreme development of such jointing is characteristic of certain flows, mainly in the upper portion of the series, which are primarily divided into vertical columns of large size and great regularity, these in turn being divided by slightly curved, nearly parallel, and very numerous horizontal partings into scaly fragments which overlap irregularly and do not extend entirely across the columns.

Another secondary parting, which has been described by Professor

Russell,[a] results in the formation of small columns perpendicular to the faces of the large vertical ones. This structure occurs where the vertical columns are irregular and especially large. In such cases the vertical cracks are comparatively wide, and probably allowed radiation and convection of heat from the sides of the columns. These were then cooling surfaces, and columns perpendicular to them were formed according to the usual law.

Lamellar parting parallel to the surface of flows is frequent near the upper and lower surfaces. This may extend for varying horizontal distances and is frequently combined with irregular vertical jointing.

FRAGMENTAL BEDS.

The beds of fragmental material thrown out from craters are made up of rough, angular, and generally scoriaceous fragments of glassy lava, imperfectly sorted, and not clearly stratified. The scarcity of such beds in the plains has been noted, and few localities can be cited where they are to be observed. In Dry Coulee, north of Adrian, a bed of red, slaggy, and porous fragments was seen, which carries water and supplies two or three springs. The north front of Yakima Ridge exhibits exposures which, by their erosion forms, appear to be coarse, fragmental basalts. To the west, as has been remarked, finer grained materials of similar nature are more plentiful, and considerable exposures are to be seen in Shushuskin Canyon and other ravines in the hills about Kittitas Valley. The fragmental materials are uncemented, very porous, and well fitted to absorb and store up large quantities of water.

MATERIALS INTERBEDDED WITH THE BASALT.

Materials other than basalt, interstratified with the lava, were observed only in the upper portion of the series. The most important of such beds is exposed in the escarpment of Saddle Mountain overlooking Crab Creek, and in the bluff opposite Craig's ferry. It is composed of fine grayish-white volcanic ash with very regular bedding, is about 100 feet thick, and is overlain by about an equal thickness of basalt. Similar ash beds in similar stratigraphic positions were observed on the sides of Kittitas, Squaw Creek, and middle Crab Creek valleys, but they do not seem to be continuous with the Saddle Mountain ash. The latter, indeed, is not observed on the west side of the river at Sentinel Bluffs, and seems to thin out or disappear to the east also.

About 500 feet below the top of the Sentinel Bluffs another light-colored bed about 40 feet in thickness is interstratified with the basalt and exposed at the same level in the cliffs on either side. This bed consists of what is known as an arkose sandstone, made up of grains

[a] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897, p. 45.

of quartz, feldspar, and mica. This rock, moderately coarse grained, friable, and of open texture, is well fitted to act as a water-bearing stratum.

ELLENSBURG FORMATION.

DISTRIBUTION.

Lying upon the surface of the basalt at numerous localities in east Washington is a series of supposed lake beds known as the Ellensburg formation,[a] from their having been first carefully studied near the town of that name.[b]

The distribution of similar beds in the same stratigraphic position is extensive, and they are found in great volume in various places in the western and the southern parts of the Columbia Plains. That these deposits are, or ever were, continuous over this broad area can not be asserted positively, but their general similarity at the various localities points to the existence of similar conditions of deposition over an extensive strip of territory east of the Cascade Mountains in the period following the close of the basaltic eruptions.

The present distribution of the Ellensburg beds in the area covered by this report is not so easy to determine as the barren aspect of the country leads one to expect. The formation is rarely exposed except where cliffs have been carved in it by ancient or modern streams, and its boundaries are mostly concealed by a thick covering of wind-blown soil. These conditions, combined with the hasty character of the work and the lack of a good topographic base, forbade anything like accurate determination of boundaries, and those represented on the map (Pl. I) are to be regarded as but roughly approximate.

LITHOLOGIC CHARACTER.

The character of the typical Ellensburg material of the Columbia Plains is shown by the following descriptive section of the exposure at the upper end of White Bluffs. The beds are described in ascending order.

Section of Ellensburg beds at White Bluffs, 1 mile below Koppen's ranch.

	Feet.
Sand, partly consolidated, and sandy clay, mostly red, weathering in part into small spheroids	25
Red tuffaceous sandstone, fine grained (ledge)	3
Soft, reddish, medium-grained sandstone	9½
Cross-bedded sand and fine gravel; fragrants mostly of scoriaceous basalt, somewhat rounded	5

[a] "John Day system" of Bull. No. 108 and Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, but so called erroneously, for the original John Day is of early Miocene age, and lies beneath the great basalt series. See Merriam, J. C., Bull. Dept. Geology, Univ. of Cal., vol. 2, No. 9, p. 276. The Ellensburg formation is probably equivalent to the Mascall formation of the John Day Valley.

[b] For detailed description of this formation in the type-region, see Smith, G. O., Ellensburg, Geologic Atlas, U. S., folio 84, U. S. Geol. Survey, 1903.

	Feet.
Fine sand and silt, with small basalt pebbles	3½
Silt, not laminated, gray to terra cotta in color, nodular in upper part	24
Fine soft sandstone, gray green to terra cotta	20
Clay, gray green to pink	15
Greenish white clay, not laminated, checking into small fragments, with feldspar grains	70
Pale terra cotta silt, not laminated	7
Greenish clay	3
Pale terra cotta silt, obscurely laminated	5
Soft greenish clay	20
Above this, but probably not of the Ellensburg formation, are:	
Gravel, with pebbles of basalt 5 inches or less in diameter, incrusted with limy material; matrix light-colored silt and sand, partly cemented with limy matter	15
Sand, lower part with fine wavy lamination, upper part with a peculiar chambered structure, having thin, highly contorted partitions of cemented sand stained with iron oxide, with soft unconsolidated sand between	15
Total	225

The general character of this section offers some points of contrast with the typical section measured in the Ellensburg quadrangle.[a] The material in the White Bluffs is much finer, coarse sandstones being rare and coarse conglomerates entirely lacking. Cross-bedding, so common in the Naches Valley section, is not common in the White Bluffs. It is evident that the material has been carried far from its source and deposited under conditions of comparative quiet.

The Naches Valley section is characterized by a very large proportion of volcanic ash and tuff, mainly of andesitic composition. The extreme fineness of most of the White Bluffs rocks makes it difficult to prove their origin, but pumice grains and clear feldspar crystals are to be seen in some of the material, and dust scraped from a specimen of very fine grain is found, by the aid of the microscope, to consist of angular transparent fragments that seem to be volcanic glass. It is believed that ash erupted from volcanoes in the Cascade Range, carried a great distance by the upper air currents, and finally falling gently into the waters of a shallow lake, form the most important constituent of the White Bluffs beds. Certain of the sandy layers, however, were probably laid down by river currents.

The writer found no fossils of any kind in the Ellensburg formation in the region examined, though it is said that shells and bones have been found in the bluffs near Pasco.

In the Moxee artesian basin the most abundant supply of flowing water is obtained from the lower part of the Ellensburg formation. The White Bluffs section also shows an alternation of relatively per-

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Washington: Water-Sup. and Irr. Paper No. 55, 1901, pp. 17–21; and Ellensburg quadrangle: Geologic Atlas U. S., folio 86, U. S. Geol. Survey, 1903.

meable and impermeable strata, which would seem favorable to the occurrence of artesian water, provided the requisite conditions of structure and supply are also present.

STRUCTURE.

GENERAL CHARACTER OF DEFORMATION.

At the close of the period during which the Ellensburg beds were deposited the rocks lay in a nearly horizontal position. Since that time they have been deformed in a manner that has a most important bearing on the artesian problems that will be discussed later on.

In his reconnaissance of a much larger area than the one here described, Professor Russell was led to the view that the characteristic orographic form of central Washington was the tilted fault block. The important economic bearing of this conclusion was recognized, as the presence of faults was held to be very discouraging to the hope of obtaining artesian water. The writer came to the field intending to investigate this point, and inclined to scepticism, for the examination of the Ellensburg quadrangle, also contained in Professor Russell's area, had shown that many of the supposed tilted blocks of the earth's crust were in reality unsymmetrical anticlines or folds in the strata.

The north face of Saddle Mountain, where it overlooks the lower stretch of Crab Creek, was cited by Russell as a very typical fault scarp. The topographic form here does indeed suggest faulting in a very striking way. South of Crab Creek a bold escarpment rises some 1,500 feet, exposing in section about 1,200 feet of basalt, overlain in order by a thick bed of white tuff, a flow of basalt, and a small thickness of Ellensburg formation proper. North of Crab Creek this lofty cliff is confronted by a low bluff of basalt, probably between 100 and 200 feet in height. A few miles to the northeast a gentle escarpment is seen, carved from the Ellensburg beds, here overlying the horizontally bedded basalt. It is obvious that we must have here either a normal fault with the downthrow to the north or a sharp flexure, the down-folded portion having been removed by erosion, leaving only the nearly horizontal strata on either side. Evidence bearing on the choice between these alternative views was gathered by examination of the Saddle Mountain front to the east and to the west of the great cliff.

On the west side of the Columbia, opposite the mouth of Crab Creek, the continuation of the mountain is bounded on the north not by a cliff, but by a steep slope, which passes continuously into the rolling surface at its base. The surface of this slope is nearly conformable to the structure of the basalt. The mountain shows no outcropping horizontal ledges, but rising through the mantle of soil,

sloping backward on the spurs and forward in the gulches, can be traced the outcrop of one or more especially resistant beds of black lava, having a dip a little steeper than the slope, but in the same direction. A little north of the base of this slope basalt can be seen with a very gentle dip to the south.

At another point, some 20 miles east of the mouth of Crab Creek, the north slope of the ridge was examined again, and a similar state of things observed. Crab Creek here flows in a canyon some hundreds of yards wide, bounded by precipitous walls about 100 feet high. Just to the south Saddle Mountain rises with a moderately steep terraced slope. For a few hundred yards back from the canyon's brink horizontal basalt, corresponding to that across the canyon, is exposed. On the lower slopes of the mountain the structure is concealed by terrace deposits and soil. Behind the uppermost terrace, however, the basalt is again exposed in a gully, where it shows a northerly dip of about 50°. The evidence indicates that there is here a sharp flexure and not a fault.

While the fact is not proved beyond doubt, the writer believes that this flexure, observed both east and west of the cliff, was once continuous along the entire front of Saddle Mountain; that the cliff along lower Crab Creek was produced by erosion, and that the flexure is here concealed below the sediments in Crab Creek bottom.

The existence of a fault along the Grand Coulee, which was asserted by Professor Russell, also appears open to doubt. In support of the fault hypothesis, Russell cites in the first place the existence of a down folding or monocline, exposed in section on the east wall of the coulee, apparently without any corresponding flexure in the opposite wall. This flexure, however, is not absent to the west, but is only obscured by the alluvial deposits laid on the terraces which have been cut in the down-folded part of the basalt. The monoclinal structure was observed in a gully northwest of Coulee City. The strike here, so far as could be observed, seemed more nearly north and south than on the east side, and the relations indicated that the monocline had been continuous across the canyon, but that the horizontal projection of its axis was probably somewhat curved. It seems unnecessary to suppose that there has been faulting. Further, the fact that the western wall of the coulee below the site of the cataract is much greater than that of the eastern wall is explained by Professor Russell as the result of faulting. To the writer it seems that this fact also could be accounted for by flexure. It is always to be borne in mind that the floor of a canyon half a mile wide and more or less covered by alluvial deposits may conceal important structures.

To sum up, it appears to the writer that the steep slopes supposed by Professor Russell to be fault scarps are, in the region considered

here, as in the Ellensburg area, the products of erosion and of sharp flexure in the basalt. It is necessary, however, in order to establish the view here advanced, to explain the remarkable fact that such important stream channels as the Grand Coulee, lower Crab Creek Coulee, and the canyon of the Columbia just below Priest Rapids have been intrenched along supposed lines of flexure. The most plausible explanation of this fact has been suggested by Professor Russell himself in one of his more recent publications,[a] in which he advances the theory that the location of the folds has been determined by the weakening of the crust through erosion along the stream courses. In other words, stream erosion, instead of deformation, has been the primary agent. This hypothesis appears to have much probability and to lend itself very aptly to the explanation of the course of lower Crab Creek and perhaps to the analogous position of the Columbia along the base of the ridge south of Saddle Mountain. In the case of the Saddle Mountain scarp, the surprise at its magnitude is diminished when we realize the fact, to be developed further on, that the Columbia, swollen beyond its present volume by water from a great glacier, once flowed in the channel now occupied by an insignificant and partly suballuvial stream.

CHARACTER OF FOLDS.

Folding is then considered by the writer as the prevalent type of deformation in the region here discussed, and he does not consider it probable that the injury of artesian basins by fissures is to be apprehended. In the western portion, lying in the foothill zone, the anticlines (structural arches) and synclines (structural troughs) are relatively pronounced, but they die out to the east, and in the wheat lands the basalt has suffered only gentle tilting, often imperceptible in amount.

With regard to direction, the folds fall into two systems. The sharper anticlines, and by far the greater number, trend nearly east and west. To this system belong the anticlines of Yakima Ridge and Saddle Mountain. Coexisting with the east-west system there are broad and gentle north-south folds, exemplified in the east slope of Table Mountain and the gentle westerly dip of the basalt underlying the wheat lands.

The form of the east-west folds is characterized by a lack of symmetry, the steeper side in the area dealt with in this paper being apparently always to the north. The contrast between the north and south faces of Saddle Mountain has been mentioned, and other more striking examples occur in the foothill region outside the area with which this report is concerned.

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[a] Russell, I. C., Geology and water resources of Nez Perces County, Idaho; Water-Sup. and Irr. Paper No. 53, U. S. Geol. Survey, 1901, p. 70.

The coexistence of two perpendicular systems of folds is perhaps favorable to the conservation of water under pressure, in so far as it tends to form basin-like structural depressions.

The specific structural features of the region whose general character has been discussed in the preceding paragraphs can be made plainer by the structure sections accompanying the geologic map than by lengthy verbal description.

PHYSIOGRAPHY.

Physiography treats of the development of the existing form of the land surface. In that development two classes of agencies have been concerned: (1) Forces, probably generated for the most part by the slow cooling and contraction of the earth, which deform the strata originally laid down in horizontal position and heave them up into the form of folds and tilted blocks; (2) the action of frost, water, ice, and wind, which modifies the masses raised up by these mountain-making forces. Agencies of the second class are mainly degrading in their effect—that is, they tend to tear down what the mountain-making forces have built up.

RELATION OF PHYSIOGRAPHY TO STRUCTURE.

The manner in which the Miocene rocks have been deformed has been discussed under the heading "Structure." The relation between this and the form of the land surface in the region considered is unusually close. There is over the greater part of the earth's surface a lack of concordance between the topography and the dip of the underlying rocks, because erosion has so deeply modified the original form of the uplifts as to make their character unrecognizable without careful study. Here, however, the principal uplifts and the basins or troughs between them have retained, in a general way, their original form. For instance, Kittitas Valley is a striking example of a structural basin in which the rock layers on all sides dip toward the center, while the portion of Table Mountain that lies within the area considered here is a structural elevation, its east face being a clear example of a "dip slope." The profile of the south face of Saddle Ridge also is in harmony with the arching structure of the underlying basalt so clearly exposed in Sentinel Bluffs. It may be said, in general, that the extensive gentle slopes in this region, unbroken by outcrops of rock ledges, are more or less nearly parallel to the underlying strata and are expressive of the structure of the rocks. In contrast to these comparatively gentle structural slopes are the bold cliffs exposing the rocks in section. These features are mainly the work of rivers, whose effect on the topography may now be considered.

WORK OF STREAMS.

The conspicuous features formed by stream erosion are the canyons of the Columbia and the Yakima with their tributary streams, and the dry coulees of the wheat lands. Less prominent are the features that represent the depositing rather than the cutting activity of the streams, namely, the gravelly flood plains and terraces. A study of the topographic forms that have resulted from the work of streams throws much light on certain of the later episodes in the history of this region.

RELATION OF STREAM COURSES TO STRUCTURE.

When we consider the relation of watercourses to the structure of the rocks, the streams of the region are divisible into two classes—those whose courses seem to have been determined by the structure of the underlying rocks, and those whose courses are independent of rock structure.

Consequent streams.—To the first class, which are technically designated consequent streams, belong the majority of the smaller streams of the region. The creek draining Willow Springs, for example, and that flowing from the Clerf Spring, flow down pitching structural troughs or synclines. Another large class of small streams or channels seem to have been located by water flowing down a structural slope. Examples of canyons originating in such a manner are afforded by the gulches draining Table Mountain and Saddle Ridge.

Antecedent streams.—The most striking examples of the second class of streams are Columbia and Yakima rivers, which in several instances cut squarely across great structural arches in the basalt. The Yakima leaves Kittitas Valley not by the lowest portion of its rim, but by a deep gorge cut across Manastash and Umptanum ridges. Lower in its course it cuts other anticlinal ridges lying outside the area of this survey. Columbia River in like manner cuts across Saddle Ridge in a direction at right angles to its crest line. Another instance is furnished by Moses Coulee, which has cut its way through the Badger Mountain uplift without regard to structure, forming a canyon whose size is especially remarkable when we consider that for ages it has not contained a perennial stream.

The formation of the gorges thus briefly described can be explained only on the supposition that the streams which formed them are antecedent to the structure, or, in other words, that their courses were established before the upfolding of the basalt and Ellensburg beds began and were maintained throughout its progress. The arches were raised up against the down-cutting rivers as a log is pushed against a whirling saw. The uplift must have been in general an extremely slow process, since in most cases there is no evidence to

indicate that the rivers were ponded, as they would have been if the rise had been so rapid that they failed to maintain their courses. The sudden uplift of Saddle Mountain would have deflected the Columbia and caused it to find an outlet over the lowest point in the dam, far to the east of the gate it actually made for itself. There is some reason to suspect, however, that the river was deflected by the next uplift athwart its course, and the eastward bend at the foot of Priest Rapids may have been due to the inability of the river to cut down against the rising ridge along whose face it flows for many miles below, to clear its lower end in the great sweep to the east inclosed on the left by the White Bluffs.

The three examples cited are not the only antecedent streams in the region. Crab Creek crosses an anticlinal arch of slight elevation below Moses Lake, while its course along the western portion of Saddle Ridge was not determined by structure. If the writer is correct in discrediting the hypothesis that the cliff in that locality is a fault scarp, the antecedent character of Crab Creek may be taken as explaining its origin, according to Professor Russell's hypothesis, cited on page 39.

ORIGIN OF COULEES.

The topographic character of the coulees in the wheat lands proves that they have been produced by stream erosion It is, however, perfectly obvious that they could not have been eroded, no matter how much time were allowed for the process, during the existence of the present arid climate. A few of the coulees have streams, perennial though insignificant in comparison with the canyons they occupy, but the majority never contain continuous surface streams, even in the rainy season. It is necessary to suppose that the coulees were eroded in a time long past, when the region had a fairly abundant rainfall. The causes which determined the formation of the Grand Coulee were, however, exceptional, and will be discussed later.

TERRACES AND GRAVEL DEPOSITS.

In the formation of their canyons the streams did not cut down steadily and without stopping. The task was accomplished in a somewhat spasmodic fashion, with alternating periods, during some of which the streams were occupied in sinking channels into bed rock, while in others they were occupied in filling with gravel those already cut. These episodes in the history of the streams are recorded in the terraces and gravel deposits of the stream canyons.

Terraces of well-rounded basalt gravel are found along all the coulees of the wheat lands, such material being especially well exposed near Connell. Similar deposits are extensively developed near Coulee City and east of middle Crab Creek and of the foot of Moses Lake. Gravel terraces are found at high levels along Columbia River, the

best examples occurring below Priest Rapids and in the gorge along the foot of Saddle Mountain. Great volumes of gravel underlie the central portion of Kittitas Valley and are well exposed in section on the banks of Yakima River.

Ancient gravels are found not only in the terraces above the present stream levels, but underlie the existing stream beds in many cases to considerable depths. At Connell records of well borings have shown that the bed of the coulee is filled with gravel to the depth of at least 180 feet. Great depths of gravel are also found in borings along other coulees. The Columbia flows on gravel through the greater portion of its channel, but has reached bed rock at Priest Rapids and perhaps also at Coyote Rapids.

The history to be read from these gravel deposits is briefly as follows: (1) There was a period during which the streams, actively cutting downward, carved a system of canyons in bed rock deeper than those which exist at present; (2) a period succeeded during which the streams were overloaded with gravel and filled up their bed-rock channels to depths attaining, in the case of the Columbia, at least 300 feet; (3) there was a second period of down cutting, in which the streams cleared out the gravel from their bed-rock channels to a greater or less extent; temporary halts in the process of down cutting are marked by the lower terraces; (4) the large and numerous streams that carved the canyons dwindled because of the arrival of the present arid climate, and the down cutting into the gravel deposits practically ceased except in the cases of Columbia and Yakima rivers.

The gravel deposits of the region are not only of scientific but also of economic interest, as the surface wells of the region are mainly located in the gravels on the valley and coulee bottoms.

GLACIAL HISTORY.

There was a period, recent as time is measured by the geologist, but long before the beginning of human history, when the valleys of the northern Cascades and of the Okanogan highlands were filled with immense glaciers, the largest of which reached the plains before they were melted in the warmer air of the lower country.

The greatest ice river of eastern Washington flowed down the Okanogan Valley, which it filled to a depth of several hundred feet. Upon reaching Columbia River Valley this glacier expanded. It seems not only to have dammed the Columbia, but to have filled its profound canyon down to the outlet of Lake Chelan, and to have spread out over the plateau embraced by the Big Bend for about 35 miles to the east of this point. The southern limit of the Okanogan glacier is marked, according to Salisbury,[a] by a terminal moraine

[a] Salisbury, R. D., Jour. Geol., vol. 9, 1901, p. 721.

extending from Chelan Falls to a point about 5 miles north of Coulee City, in a great curve convex to the south.

The eastern end of this moraine was seen in the course of this investigation. It is a low ridge or, more exactly, a slightly elevated hummocky zone formed of material pushed up in front of the advancing glacier or carried on its surface and stranded where the ice melted. Borne thus upon the southward-moving ice were many huge blocks of basalt and fewer of granite. Some of these were stranded upon the moraine, and many are to be seen on the plateau in the vicinity of St. Andrew. One of them, an enormous block of basalt, stands near the brink of the Grand Coulee and is a striking landmark visible for many miles. In early days it served to guide travelers from the east, and was generally known as Pilot Rock. Other large bowlders are strewn upon the terraces at Coulee City and Ephrata, and seem to have been dropped from icebergs that broke from the glacier front and floated for some distance southward on the stream which then filled the Grand Coulee.

While the Columbia was dammed by the Okanogan glacier it flowed along its western side southward into Crab Creek Valley, which was probably eroded to a considerable depth before this time. During the existence of the ice dam the Grand Coulee was carved, lower and middle Crab Creek Valley was much enlarged, and extensive deposits of gravel were laid down about Ephrata and Moses Lake. When the glacier retreated up Okanogan Valley the Columbia resumed its former channel.

WIND WORK.

Under the arid conditions that have prevailed in historic time water erosion has had comparatively little effect in modifying the general surface of the land. Various conditions, however, have enabled the wind to do considerable transportation; the air currents, which have a prevailing southerly direction, are strong and frequent, while the soil is dry and loose textured, and is but slightly protected by the meager growth of grass and shrubbery.

SAND DUNES.

The most striking evidences of wind work occur in the sandy region that borders the Columbia, where groups of sand dunes of very perfect form are to be seen. They exhibit the characteristic wave-like profile, their steep sides constantly facing in the north or leeward direction, and the process of their growth and shifting is to be seen on any windy day. Other sand dunes of remarkable size and extent are to be seen below Moses Lake, which, as before remarked, owes its existence to them. Low hillocks, built up mainly by wind action, are also to be seen on the plain south of Saddle Mountain, but the dune form in these is not so pronounced as in the

A. GRAND COULEE.

B. RECLAIMED MARSH LAND NEAR WILSON CREEK.

ones previously mentioned, probably because of the vegetation that has found a foothold upon them and allows the sand to move less freely.

SOILS OF THE WHEAT LANDS.

In the wheat lands also the wind has given the final touches in the molding of the surface. The minor branches of the dry coulees, carved originally from basalt, have had their once rugged sides mantled with fine wind-blown soil, which conceals the bed rock except in widely separated exposures. That the soil mantling the slopes of the coulees has been laid down by wind seems obvious. The present writer further believes that the thick soil of the wheat lands also is mainly wind deposited, or eolian. It has been assumed by most writers who have touched upon the subject that the typical wheat soil of the Columbia Plains is residuary, derived from the decomposition of the underlying basalt. Professor Russell, however, is the only geologist who has supported the residuary hypothesis by extended argument. In his report on southeastern Washington he advocates the view that the wheat soils are essentially residual, but superficially modified by wind action.[a] In his later description of the Nez Perces region in Idaho he reaffirms the views expressed in the earlier paper, and applies the theory of residuary origin to the wheat soils of Idaho.[b] The writer's observations in east-central Washington have led him to believe that the wheat soils are not residuary, but wind deposits. This belief is based primarily on the following facts observed in the field:

(1) The thickness of the wheat soils, as shown by well records, varies according to location from 50 feet to a minimum probably averaging something like 25 feet. They mantle completely most of the broad plateau surface and the gentle slopes, often concealing the bed rock in the smaller gullies for many miles. The greatest thicknesses, however, seem generally to be on the brows of slopes, where there are the most favorable opportunities for accumulation of wind-blown material.

(2) The physical properties of the wheat soils are highly characteristic and remarkably uniform. In texture they are fine loams, very light, open, and friable.

(3) Their prevailing color is a light tawny brown, varying according to the amount of organic matter present, but conspicuously in contrast to the deep red tints which one would expect in a soil derived from the decomposition of a rock so rich in iron oxides as basalt.

(4) When exposed in vertical sections the wheat soil is seen to preserve its surface characters with remarkable constancy down to the

[a] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897, pp. 60-64.

[b] Russell, I. C., Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 53, U. S. Geol. Survey, 1901, pp. 44-48.

solid basalt beneath. There is rarely any lamination perceptible, such as would suggest deposition by water.

(5) In all sections observed by the writer, moreover, the division between the basalt and the tawny loam is sharp, without any transition from fresh rock, through decomposed rock and soil with rock particles, such as would be expected were the soil residuary.

The sharp definition between soil and basalt seems absolutely to forbid the belief that the soil is residuary in the strict sense—that is, resting in the place of its formation. It must, therefore, be a transported soil. The absence of lamination in the soil, the fineness of its texture, and the absence of any particles so large as to be incapable of wind transportation seem almost to demonstrate that the agency concerned in its deposition was wind. Granting this much, however, it might still be argued that the material was derived from the decomposition of basalt and only slightly removed from its source. But the wheat soil's evident poverty in iron oxide, and its freedom from any recognizable particles of basalt, are facts which strike the observer in the field as discordant with such a supposition, and the results of detailed chemical analyses give additional evidence in the same direction.

Comparative analyses.—There are on record many analyses of the wheat soils of the Columbia Plains, made in the agricultural experiment stations of Washington and Idaho. It appears, however, that they are generally analyses merely of the portion soluble in hydrochloric acid, and while they may serve the purpose for which they were made they do not give the true chemical composition of the samples and throw but little light on the question of their origin. Partial analyses of basalt and of the overlying soil from Dayton, Wash., have been made by Dr. G. P. Merrill and are published by Professor Russell,[a] but the soil analysis differs so markedly from all those emanating from the experiment stations as to throw increased doubt upon their availability.

In view of these facts analyses were made in the chemical laboratory of the Geological Survey of a typical wheat soil and of an undoubtedly residuary soil. The following tables are designed to facilitate the consideration of the available chemical evidence bearing on the origin of the wheat soils. In Table A the results of the last-mentioned analyses are exhibited side by side with an analysis of basalt similar to that underlying the wheat lands from the Mount Stuart, Washington, quadrangle. In Table B the analyses given in the first table are presented in a condensed form for more ready comparison with the analyses given by Professor Russell.

[a] Russell, I. C., Reconnaissance in southeastern Washington: Water-Sup. and Irr. Paper No. 4, U. S. Geol. Survey, 1897, p. 61; and Geology and water resources of Nez Perces County, Idaho: Water-Sup. and Irr. Paper No. 53, U. S. Geol. Survey, 1901, p. 44.

TABLE A.—*Analyses of basalt, residuary soil, and wheat soil made in Geological Survey laboratory.*

	I.	II.	III.
SiO_2	54.50	52.95	65.43
Al_2O_3	14.43	15.69	13.96
Fe_2O_3	2.17	[a]11.85	[a]5.35
FeO	8.80		
MgO	4.24	2.05	1.54
CaO	8.01	4.40	2.90
Na_2O	3.05	2.09	2.42
K_2O	1.29	1.11	2.08
H_2O at 105	.29	2.19	2.32
H_2O above 105	1.09	4.01	2.42
TiO_2	1.69	2.57	.87
P_2O_5	.21	.19	.20
C	.....	.63	.49
Total	99.77	99.72	99.98

[a] Comprises all iron oxide reckoned as Fe_2O_3.

I. Basalt, Mount Stuart quadrangle; Hillebrand, analyst; contains also small quantities of SO_3, MnO, BaO, and SrO, aggregating 0.36 per cent.

II. Residuary soil, Hanson Creek; Steiger, analyst.

III. Virgin soil (surface), south of Krupp, Wash.; Steiger, analyst.

TABLE B.—*Analyses of Table A (condensed) compared with analysis given by Professor Russell.*

	I.	II.	III.	IV.	V.
SiO_2	47.35	54.40	52.95	65.43	63.58
Al_2O_3, Fe_2O_3, etc	[a]34.38	[a]28.28	[a]30.30	[a]20.38	[a]22.36
MgO	4.43	4.24	2.04	1.54	1.82
CaO	8.27	8.01	4.40	2.90	2.76
Na_2O	2.55	3.05	2.09	2.42	2.02
K_2O	1.33	1.29	1.11	2.08	2.27
Ignition	.95	1.38	6.83	5.23	4.37
Total	99.26	100.75	99.72	99.98	99.33

[a] Comprises all iron oxide reckoned as Fe_2O_3, plus the P_2O_5 and TiO_2.

I. Basalt; Merrill, analyst; given by Russell.

II. Basalt, Mount Stuart quadrangle; Hillebrand, analyst.

III. Residuary soil, Hanson Creek; Steiger, analyst.

IV. Virgin soil (surface), south of Krupp; Steiger, analyst.

V. Surface soil, wheat field near Dayton, Wash.; Merrill, analyst; given by Russell.

Upon comparison of the analyses in Table B it is evident that I and II are very similar, and in view of the fact that the basalts of the Yakima series do not vary widely in petrographic character, analysis I in Table A may be taken as sufficiently representative of the basalt series for the present purpose. The similarity also of the soil analyses IV and V is astonishingly close and strongly suggests that the two soils are of the same nature. Comparison of the analyses in Table A should therefore give some valid evidence in regard to the general question of the origin of the wheat soils.

A mere glance at the table shows a general similarity between I and II and a general dissimilarity of III from either of the others. When we proceed to more detailed comparison of the proportions of the various oxides, the most significant facts brought out seem to be the following:

(1) The alumina in III is slightly less than in I and II.

(2) The iron oxides are about equal in I and II, but are much less abundant in III.

(3) The alkalies in II show, as compared with I, a notable decrease, relatively greater in the case of potash; III contains little less soda than I and more than II, while the potash is 60 per cent more abundant than in I.

Residuary soils generally show, as compared with the parent rocks from the decomposition of which they are derived:

(1) Increase in the proportion of alumina. In calculating the percentage of each constituent lost in the process of decomposition the alumina is generally assumed to remain constant.

(2) Equally or more abundant iron oxide, except where organic matter is present and reduces the iron to the soluble protoxide. There is no evidence, however, that the conditions in this region ever favored the removal of iron oxides by leaching.

(3) Greatly decreased percentage of alkalies, which are the most soluble constituents of the rock.

It is sufficiently obvious that the differences between the wheat soil and the underlying basalt are not only considerable, but, what is much more significant, are not of the character naturally to be expected if the wheat soil were derived from the basalt. The discrepancies between the facts of the case in point, on the one hand, and the usual results of weathering, on the other, if they do not quite invalidate the residuary theory, at least require explanation. In the writer's opinion, the chemical data available appear to agree with the field observations in supporting the theory that the soils in question were not derived from the decomposition of the basalt.

Transporting power of the wind.—The competency of the wind as a transporting agent must be considered, however, in judging of the validity of the theory here advanced. That wind is, in the Columbia

Plains, a transporting agent of importance is a fact which must impress anyone who travels through the region. Winds of prevailing southerly direction blow with strength and frequency, while the soil is but very imperfectly protected from them by vegetation. Blinding dust storms are by no means rare, and clouds of fine dust envelop every traveler who drives along the roads. On the whole, there appears no reason to doubt that the wind is capable of doing the work assigned to it under the hypothesis here advanced.

Source of the soil.—The argument, however, would not be complete without suggesting a source for the material if we reject the supposition that it was mostly derived from basalt. The writer believes that the principal source lies in the desert southwestern quarter of the Columbia Plains, where the basalt is overlain by the soft sedimentary beds of the Ellensburg formation. This material is thought to have been washed down and loosened by the agency of water, and thus put in such form that it might readily be transported by wind.

HYDROLOGY.

INTRODUCTORY STATEMENT.

The remainder of this paper is devoted to the consideration of water supply proper. The various kinds of water resources will be described and their availability considered, and the attempt will be made to show how the water supply of the region may be increased. The sources of supply available in the region are streams, springs, and wells, which will be considered in the order named. The first two classes of water resources will be treated rather briefly, but the wells, being more important, will be discussed more fully.

The wells may be divided into two classes—first, surface wells, generally dug by hand in loose materials like soil, sand, and gravel, lying on the surface of the bed rock; second, deep wells, including those in which the underlying older rocks are penetrated, generally by means of a dril, to a considerable depth. Surface wells derive their supplies from rain or snow that falls in their immediate vicinity and percolates downward until some impervious material is reached, while deep wells generally tap beds of porous rock saturated with water that has been absorbed at some distant outcrop and has traveled underground often for great distances.

The most important question dealt with in this paper is that of the capabilities of deep wells, one of the principal objects of the investigation having been to determine whether in any part of the region examined deep wells could be made to yield artesian flows. In discussing this problem a number of districts may be marked out, in each of which the conditions affecting the deep underground waters are similar. For each of these districts the artesian conditions will

first be discussed from the theoretical standpoint; the evidence afforded by the wells actually sunk will then be presented, and conclusions will be drawn in regard to the probability of obtaining surface flows. Suggestions will next be presented with a view to directing intelligent tests for artesian water and to economically using all the water obtainable. The paper will end with a brief recapitulation of the important conclusions and suggestions in regard to deep wells.

The preceding portions of this paper have been designed mainly to serve as an introduction to the portion on hydrology proper, as the discussion of the artesian problems will involve frequent reference to the facts regarding the character and structure of the rocks underlying the region.

STREAMS.

COLUMBIA PLAINS.

CRAB CREEK.

From the fact that the valley of Crab Creek was eroded by a much larger stream than occupies it at present it has resulted that the existing stream has been unable to maintain a graded channel. Certain irregularities in the ancient channel and modifications produced by the drifting in of sand and silt have been sufficient to cause ponding in certain localities, with the consequent formation of marshes, and in some cases the water of the creek vanishes during at least a part of the dry season beneath porous surface deposits, to reappear in full force at a lower point.

The meadows used for the growing of hay and as pasture are generally sufficiently watered by the underflow of Crab Creek, but in certain localities ditches have been constructed to water portions of the bottom too high to utilize the underflowage.

On the other hand, some considerable areas of marshy land have been or are being reclaimed by drainage, a notable instance being afforded by the marshy tract extending from Krupp to Wilson Creek. This is being gradually drained, and a large amount of certain localities ditches have been constructed to water portions of the bottom too high to utilize the underflowage.

COLUMBIA RIVER.

The use now made of Columbia River water, in its course through this region, is comparatively insignificant. A small amount of water is raised by water wheels, three or four of which are situated on the right bank of the Columbia below Priest Rapids. The availability of this method is limited by the comparatively small amount of land low enough to be watered by such means. In only one

instance is any other means of irrigation used. This is in the case of the Babcock ranch, near Trinidad, where one of the lower terraces has become the site of a hay ranch, which is irrigated successfully by means of a gasoline pump and a number of windmills.

It is natural for the traveler in this region to be disappointed at the slight utilization of Columbia River water and to inquire into the possibility of bringing more of it upon the bordering arid lands, especially the extensive tract between the Saddle Mountains and the easterly stretch of the Columbia, the general elevation of this tract being about 300 to 400 feet above the Columbia at Sentinel Bluffs.

Two possible methods of accomplishing this suggest themselves. The first involves the construction of a ditch from some point on the upper Columbia or on some tributary of the Columbia. This idea, when scrutinized, offers great engineering and financial difficulties. To reach a point on the Columbia of sufficient elevation would necessitate the construction of many miles of flume along precipitous portions of the river gorge. To bring water from one of the tributaries flowing into the Columbia from the Cascade Mountains on the west would involve obstacles which, if less serious than those presented by the first-mentioned plan, would still be extremely formidable.

The second apparently possible method is to raise the water from the Columbia by pumping, obtaining the power by utilizing the considerable fall of the river through Priest Rapids. The practicability of such a scheme must be determined by experienced engineers after examination of the ground, and the suggestion is made here only tentatively.

It is said that surveys were once made for a ditch to head at Sentinel Bluffs, with the hope of irrigating a large part of the sandy land below the great bench, but it was found that the ditch level abutted against the escarpment of a terrace about 150 feet above the river and fairly close to its shore at a point a few miles east of the Harrison ranch. The project was therefore abandoned, as it was considered that the small area of land irrigable by such a ditch would not justify its construction, while to secure an increase of elevation sufficient to overcome the obstacle mentioned would require that the ditch be begun above the Sentinel Bluffs and far up the rocky gorge north of Crab Creek.

KITTITAS VALLEY.

YAKIMA RIVER AND TRIBUTARIES.

The greater part of the arable land in Kittitas Valley is more or less efficiently irrigated. The ditches may be divided, according to the source from which they derive their supply, into two classes: (1) those leading from Yakima River, and (2) those obtaining water from the tributary streams that head in the mountains to the west,

north, and east. The ditches of the first class are nearly all controlled by corporations, and data concerning them are comparatively accessible. Those of the second class include only two incorporated ditches and a large number of private ditches, concerning which it is difficult to obtain accurate information.

Canals from the Yakima.—The oldest large canal on Yakima River is that known as the Ellensburg ditch, controlled by the Ellensburg Water Company. The construction of this ditch was begun in 1885, and the greater portion of it was completed in 1887. It was enlarged and extended 3 miles in 1892. The cooperative plan upon which the controlling corporation was organized is typical for the Ellensburg region.

The ditch was built by the farmers in the irrigation district covered by the ditch, stock in the corporation being given in payment for the labor performed. The original value of the stock was placed at $5 per share, of which 8,000 were issued. The ownership of each share entitles the holder to one-half a miner's inch of water. The price of water is fixed each year and the money received applied to the payment of current expenses, which are low, and to the liquidation of indebtedness incurred in the construction of flumes. The present price of water is about $1 per inch, or 50 cents per acre, but it is expected, after the indebtedness is cleared off, to reduce this to about 50 to 70 cents per inch.

The intake of the canal is at a point on Yakima River about 7 miles above Ellensburg. It sweeps about the eastern side of the valley, doing duty for most of its entire length of about 20 miles, and terminates at a point about 5 miles southeast of Ellensburg. Its fall is 22 inches to the mile. The total area irrigated by this canal is about 8,000 acres.

The Bull canal is named for Walter A. Bull, by whom it was first constructed in 1885 for the irrigation of his own farm. It was afterwards enlarged and used by a score of farmers, who organized a corporation, to which the water rights of the ditch were transferred in 1898. The plan of organization was cooperative, and similar to that of the Ellensburg Water Company. There are 50 shares of capital stock, each valued at $75 and entitling the holder to 20 inches of water. The capacity of the canal is thus about 1,000 inches, or sufficient for the irrigation of some 2,000 acres. The charges for water are extremely low. They average about 20 cents per inch per annum, and attained in 1898 the merely nominal figure of 5 cents per inch.

The water is taken from Yakima River, and first does duty in supplying power for the flour mill at Ellensburg. From the tailrace of the mill the water is led into the lower part of Wilson Creek channel, and this natural trench is made to serve the purposes of a ditch.

The only other large ditch from Yakima River is that of the West

Side Irrigation Company, which begins about 2 miles above Thorp and irrigates about 7,000 acres on the west side of the river. It has a capital stock of $30,000, divided into 600 shares of $50 each. A share entitles its holder to 6 inches of water. The cost of maintenance is about $1,000 a year, or about 35 cents per inch of water delivered.

The Cascade Canal Company has just completed a canal higher than any previously constructed. It has been financed locally and is to be operated on cooperative principles. The intake of the canal is at Dudley, about 4 miles above Thorp, and its total length is about 42 miles. The company has built a dam across the outlet of Lake Kaches that will raise the water about 15 feet above low-water mark. The cost of the canal is about $125,000, and it will irrigate about 16,000 acres of land. The same company expects to construct a higher canal in the near future.

Canals from tributaries of the Yakima.—Of the canals that take water from the mountain streams, only two are incorporated. These are the Taneum and the Manastash ditches, named from the streams from which they derive their respective supply. They are among the oldest ditches in central Washington, both having been constructed about 1875.

The larger of these is the Taneum ditch. It was constructed on a cooperative plan. The cost of construction was a little more than $1,000, and the corporation was capitalized at $2,000, divided into 40 shares. The value of water is so great, however, that $500, or twenty times the par value, is now paid for a single share. The capacity of this ditch at high water is about 5,000 inches, but the supply often becomes deficient in late summer.

The Manastash ditch irrigates a smaller area than the Taneum. Its maximum capacity is 1,200 inches; after July 1 the supply is cut down to half this amount. The capital is about $1,500, but the actual value of the ditch is now estimated at about $25,000.

In addition to the canals above described, there are a great number of private ditches taking water from the small streams. It is supposed that the total acreage irrigated from these ditches is larger than that supplied by the larger incorporated ditches. However, those who are dependent on the supply of the mountain streams often suffer from an insufficiency of supply in the latter part of the summer, there being generally no more than enough to mature grain or a single crop of alfalfa.

CONSERVATION OF THE SUPPLY.

For the amelioration of this condition it is to be hoped that storage reservoirs in the mountain canyons may be constructed at some future time, so that the abundant run-off of the rainy months can

be stored and allowed to come down to the thirsty valley lands in the dry season, when it is needed. The writer is unable to suggest any sites where reservoirs can be constructed economically, but believes that future necessity may stimulate the discovery and survey of suitable reservoir sites.

It is also a matter of the highest importance to make certain that the means supplied by nature for the equalization of the run-off by the storage of water in snow banks and in the sponge-like mantle of humous soil and rootlets that is spread over the shaded forest areas shall be preserved to the fullest possible extent. It is probable that the regulations in regard to the pasturing of sheep in the forest reserves might advantageously be made more stringent. Greater pains should also be taken to prevent the spread of forest fires and to secure the punishment of those who start them. There can be no doubt that the origin of a great number of forest fires is traceable to criminal neglect, if not to the deliberate intention of those whose interest is furthered by the clearing of the land. There is much testimony to the usefulness of the foresters in checking forest fires, but it is also certain that the present force is inadequate to prevent immense annual destruction under existing conditions.

SPRINGS.

In the early days of the settlement of the arid Columbia Plains water for the use of man and beast was almost entirely derived from springs. Even up to the present time many families are entirely dependent upon springs for their supply, which they not infrequently haul for many miles either in barrels or in specially constructed tank wagons. The more provident farmers have cisterns sufficiently capacious to contain several tank loads, and are thus enabled to hold a supply in reserve to tide over periods when time can not be spared for hauling.

The springs of this region may be classified as surface, canyon, and fissure springs. The great majority belong to the first two classes.

SURFACE SPRINGS.

The term surface springs is applied here to springs in surface deposits overlying the basalt, supplying water that has not sunk to any considerable depth. These in many cases appear to be formed by the gathering of surface water that has percolated down through the soil mantle and, flowing slowly over the underlying surface of comparatively impermeable rock, has become concentrated in the stream channels that furrow its surface. The water, small in amount, is for the most part concealed in the alluvium and the wind-blown silt with which these channels are filled, and emerges only in excep-

tionally favorable localities. Springs of this character are observed on the line of the Northern Pacific at Paha, and are of especial importance on the slope leading from Coulee City to the plateau northwest. It is probable that at this locality they are largely in the material of the great moraine that terminates in this neighborhood. In the sloping gullies these springs are numerous enough to furnish the domestic supply for the ranches there situated.

CANYON SPRINGS.

What are designated canyon springs are generally situated in the walls of coulees. In genetic character they do not differ widely from springs of the first class. The water supplying them has come from no great distance. In some cases they are supplied by rain water that is absorbed by the soil and finds its way slowly through crevices in the columnar basalt to a porous layer of scoria underlain by relatively impervious rock; favored by a slight slope, the water then flows to some outlet in a canyon wall. In other cases it is probable that much of the supply is absorbed at another edge of the water-bearing stratum exposed on the slope of a not far-distant canyon from which there is a decided dip toward the spring. Black Rock Spring, in the first coulee south of upper Crab Creek, appears to be a case in point. The water there rises, apparently under slight pressure, through the alluvium at the base of the northern wall of the coulee. At Wilson Creek, on Crab Creek just north of this spring, the basalt has a dip of 5° to the south, and it is possible that some water falling on the side of Crab Creek Canyon finds its way to Black Rock Spring.

The number of canyon springs observed was very large. In the valley of Crab Creek near Krupp a spring in a small gully has been improved by digging, and by a system of piping has been made to supply excellent water to a house and barnyard. One of the most important springs in the region is that known as Skooten Spring, which is situated near the eastern end of Saddle Mountain, and supplies a small pond without outlet, and consequently strongly alkaline. There is no other surface water within some 15 miles, and therefore the horses that graze within that radius resort to this watering place in great numbers.

Professor Russell has suggested a method of increasing the flow from the springs that issue from sedimentary layers in the basalt series by driving horizontal tunnels in the water-bearing strata. No springs improved in this way were observed, although small well-like pits have been sunk in many places. It is probable that horizontal tunneling might be employed to advantage in many cases, but the springs generally seem to occur in comparatively thin layers of

scoriæ or cinders, so that the digging of a tunnel would be considerably retarded by the resistance of hard rock above and below.

There is a water prospect of peculiar history on the northeastern slope of Saddle Mountain. Tradition has it that the sounds of rushing water used to attract the attention of passers-by, and tunneling was undertaken in the hope of tapping the subterranean stream. The writer visited the abandoned and caved-in excavation, which had penetrated only the mantle of soil and basalt rubble, but could not detect the faintest whisper of the alleged underground current.

FISSURE SPRINGS.

There remain to be described two very large springs, one of which is certainly a fissure spring from a deep source, while the other is only doubtfully to be classed as a fissure spring. The first of these is Clerf Spring, in Kittitas Valley, the second is a group of springs on a terrace of the Columbia overlooking the foot of Priest Rapids.

CLERF SPRING.

The salient features of Clerf Spring have been mentioned by Mr. George Otis Smith.[a] It is situated at the side of a small canyon emptying into the east end of Kittitas Valley. The natural flow has been increased about fourfold by an excavation that affords a good exposure of the rocks from which the spring issues. Fine shales and shaly sandstones of the Ellensburg formation here rest upon the vesicular surface of a basalt flow. The water boils up from the bottom of the excavation, which has penetrated the basalt to a slight extent, and probably emerges from crevices in the rock concealed by fine débris. The water is of good quality, but noticeably warm, the temperature being 62° F. An irrigating ditch leads from the spring along the side of the canyon to the side of the main valley. The supply from this fountain, which is all utilized in the dry season, is estimated to be about 120 miner's inches.

The high temperature of the water and the mode of its emergence show that this spring is, in effect, a natural artesian well and that its water is forced up by hydrostatic pressure from a considerable depth. The facts point unmistakably to the existence in this vicinity of conditions favorable to obtaining flowing artesian water. An experiment in this direction has been made, and boring has been begun within a few rods of the spring in the hope of obtaining an additional supply of water. The well has been carried to a depth of about 40 feet in the basalt, and water has been obtained which, on a test, rose just above the surface. The drilling was done with poor machinery

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Washington: Water-Sup. and Irr. Paper No. 55, U. S. Geol. Survey, 1901, p. 45.

and evidently by an inexperienced driller. The progress in the solid basalt is said to have generally been less than a foot a day, or about one-sixth of the rate attained by experienced drillers in the wheat country. The well was finally abandoned and has caved in about the top so as to be at present useless.

HARRISON SPRINGS.

At the southwest extremity of the arid plain that stretches south from the base of Saddle Ridge there is a strip of land about 3 miles long by one-half mile wide which is green with a luxuriant growth of swamp hay. On the border of this oasis there are clustered a group of farm buildings and corrals and a strip of old orchard, flourishing and bearing abundantly. A large force of farmers and cattle men live upon the place, which is generally known as the Harrison ranch.

Along a line in the central part of the hay meadow there are a number of small ponds bordered with tules and other aquatic plants. The ponds are very deep in proportion to their small area, and are perennially supplied from beneath with living water colder than that of the river and of good quality. The overflow originally escaped to the river from both ends of the meadow, but since the east end is now banked by a sand dune the escape is mainly to the west, where it falls over the terrace in a stream of probably several hundred miner's inches.

In its original state the area now occupied by this oasis was a marshy lake, which has only been made available for agriculture by artificial drainage. Even now the meadow land beneath the surface is saturated with water and quakes in many places beneath the foot. It is therefore unfit for growing grain or alfalfa. The present crop is chiefly of wild swamp hay, but an endeavor is being made to improve the quality of the forage by gradually supplanting it with domesticated grasses. The crop is mainly used on the ranch for the winter feeding of cattle and horses, whose summer range extends over a large part of the desert to the north. About 1,500 head of stock were wintered here in 1901–2.

The waste of the large surplus of water from these springs, in a land where water is so precious, must strike anyone as a thing to be regretted, and gives rise to the inquiry whether more of it might not be used. The hope of this does not appear to be very good. The strip of land between the meadow and the river is not in general more than 5 feet above the springs, and might, perhaps, be irrigated readily by windmills, but the soil is very gravelly and apparently infertile, so that it is doubtful whether the expense of irrigating it would be repaid. The ranch is situated on the lowest terrace above the actual flood plain of the river, and there seems to be little or no land that can profitably be irrigated from the springs by gravity alone. On the

other hand, however, it appears possible to extend the area of hay land by draining some of the broad shallow ponds at the eastern end of the meadows.

The geologic conditions which give rise to these springs can not be observed directly, for the bed rock in this vicinity is mostly concealed. A few small outcrops of basalt are seen north of the oasis, and this rock forms the bed of the river at Priest Rapids. The riverward escarpment of the terrace upon which the springs are situated

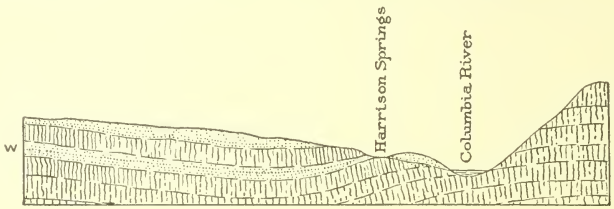

FIG. 2.—Section illustrating explanation of Harrison Springs on the hypothesis that the water-bearing stratum has been tapped by erosion.

is of gravel, without rock exposures. The rock from which the water issues is not exposed. From the rather meager observations two explanations of the phenomena observed seem possible. Under either hypothesis the water is supposed to flow from some porous reservoir stratum (possibly the white tuff bed exposed near Sentinel Bluffs) fed by rain and snow falling on Saddle Mountain.

According to the first hypothesis, illustrated in fig. 2, the water-bearing stratum has been tapped by erosion. The fact that the water issues along a comparatively short line may be explained on the sup-

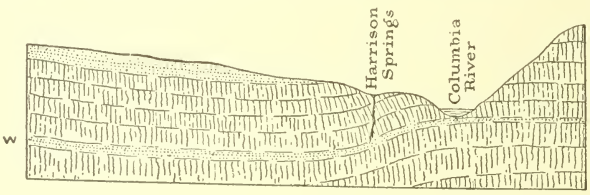

FIG. 3.—Section illustrating explanation of Harrison Springs on the hypothesis that the springs are situated along a break in the basalt.

position that the water-bearing stratum is lenticular, and that a tongue-like projection has been cut off here. The tuff bed already mentioned appears, indeed, to have a lenticular form, since it is not seen west of the river at Sentinel Bluffs nor south of it at Priest Rapids.

An alternative explanation may, however, be given for Harrison Springs. (See fig. 3.) The fact that the springs are in a straight line parallel to the structural ridge across the river strongly suggests that they may be situated along a break in the basalt formed by the

earth forces that produced the ridge. This hypothesis is, perhaps, on the whole, somewhat more probable than the one already given. The coolness of the water, however, shows that it does not come from a great depth. The fracture, if it exists, may therefore be a minor one in the basalt above the water-bearing stratum, produced by the rather sharp bending of the basalt and not extending indefinitely downward like a true fault fissure.

SURFACE WELLS.

The numerous farm wells in Kittitas Valley belong mainly to the surface type and are sunk in valley alluvium. There are some, however, which penetrate Ellensburg sandstones for short distances and probably derive their supply from distant sources, thus being classifiable genetically with the deep wells. Their discussion, therefore, will be deferred to a later section.

The surface wells proper of the valley perhaps require no description. The few wells very near Columbia River, and the more numerous ones in Crab Creek bottom, which derive their supply from the underflow of the neighboring streams, may also be passed with brief mention.

The great majority of the shallow wells in the Columbia Plains are sunk to depths varying from 13 to 75 feet in the alluvial deposits that floor the dry coulees and their tributary gulches. The suggestion advanced in the discussion of springs, that the water on reaching bed rock has been concentrated in the old subsurface channels according to natural laws of drainage, is equally applicable in the case of these wells, for the nature of springs and of surface wells is, in fact, essentially the same, save that in the former the configuration of the ground is such that the water-saturated bed emerges on the surface.

A notable well of this class supplies the small village of Ephrata. Just west of the town a canyon opens out upon the gravelly plain. There is a small surface flow in the lower part of the canyon, which vanishes in the broad delta-like alluvial fan below its mouth, where a shallow well taps the sunken stream, and a windmill pumps it into a tank, from which it is distributed through a system of pipes. There are several other wells in the neighborhood of the town, generally from 50 to 75 feet deep, and gathering their supply from gravel that was probably laid down by the Columbia in Glacial time.

Of more especial interest are the fairly numerous wells on the plateau west of Coulee City. These have all been dug by hand, for the most part in the sand, clay, and gravel brought down by the ancient glaciers from the north. Two such wells are situated in sec. 14, R. 25, T. 27 E., one of which penetrates 42 feet of gravel, clay, and sand and 18 feet of basalt, while the other attains a depth of 65 feet without reaching basalt.

The quantity and stability of the supply from surface wells vary widely in different cases. The wells last mentioned appear to meet all demands except when the wind for the windmills fails for a considerable time. The wells in the coulees often give an abundant supply; one in Lind Coulee, notably, met the domestic needs at one time of a score of families. On the other hand, some surface wells often fail to meet the demands made upon them in the dry season, and it may be said in general that the chances of obtaining a generous and reliable supply of water are smaller in surface wells than in deep borings in the basalt.

DEEP WELLS.

INTRODUCTORY STATEMENT.

Historically the deep well represents the latest development in the methods of obtaining water on the Columbia Plains. When the fertility of the plateau lands was recognized their settlement became inevitable, but the question of water supply was at first a serious one. The waste of time and labor involved in hauling from the widely scattered springs, often necessitating the pulling of a heavy tank over miles of deeply rutted and hilly road, led the wheat growers to seek a method by which a sufficient supply of water could be obtained at any desired point, even upon the summits of the plateau. The deep drilled wells solve the problem successfully, and they are being put down by all who are able to meet the expense, which is often considerable.

The charges for well drilling in the southern part of the wheat lands are as follows: In soil, gravel, etc., above basalt, 50 cents a foot; in rock (which is generally in great part massive basalt, though other varieties after the first basalt is struck are not differentiated), $2.25 per foot for the first 300 feet and 50 cents per foot additional for each 100 feet below that depth. Water for the engine, coal, and board for the outfit are furnished by the owner of the ranch.

In the vicinity of Ritzville the terms are slightly higher; for the first 300 feet the charge is there $2.50, and 50 cents higher for each additional 50 feet. On these terms, however, the driller furnishes coal, the cost of which is estimated at about 25 cents for each foot drilled in basalt. In all cases water is guaranteed, and the risk of losing tools (which generally also necessitates abandoning the hole) is borne by the driller. The average cost of a well at these rates is probably not far from $800, though it reaches a maximum of over $2,000.

The rates charged for drilling appear fairly reasonable considering the cost of machinery, the risk of loss, and the degree of skill required. The hardness of the rocks is such as to call for very careful tempering of the drills and skill and patience in manipulation.

There seems to be a strong personal factor in the success of drilling operations, many drillers having records unmarred by loss of tools or failure to obtain water, while the work of others seems frequently to end in disaster.

In Kittitas Valley deep wells have never attained importance as a source of water supply. This fact is due to the more favored condition of the valley. In the lower portion shallow hand-dug wells have been found adequate to supply the wants of the house and barnyard. The much larger demands of irrigation have been supplied more or less satisfactorily with water from the Yakima and its tributaries. Thus, although it has long been recognized by intelligent observers that the basin-like structure of the valley is favorable to artesian water, the demand for an artesian supply has not been strong enough to give rise to energetic prospecting. The two borings that have been made were unsuccessful and have thus tended to destroy the hope of obtaining flowing wells in the valley, but, as will be shown later, these experiments were so inefficiently carried out as to have little evidential value.

The purpose of the following discussion is primarily economic, and it will attain its object if it helps the reader to decide to what extent he can profitably invest in deep borings. It is the scientific questions involved in this problem that the writer proposes to treat here. It will be shown, for one thing, to what depths, approximately, it is necessary to go in a given part of the district for a sufficient supply. But a question which is perhaps more important, and whose solution requires scientific investigation of a special kind, is whether artesian water exists in the region. The fact that no flowing wells exist at present is not conclusive evidence for a negative answer to this question, since the all-important rules for the proper casing of wells have been generally ignored. Furthermore, an endeavor will be made to show that underground pressure, even though insufficient to raise water to the surface, may often advantageously be utilized by proper casing.

Since this paper is intended chiefly for the benefit of nonscientific readers, it will be necessary, in order to make the discussion of artesian problems clear, to insert at this point a statement of the principles upon which artesian flow depends, and to show how those principles should be applied in prospecting for artesian waters and in constructing artesian wells.

GENERAL THEORY OF ARTESIAN WATER.

The conditions that usually determine the flow of an artesian well may be illustrated as follows: Suppose two water-tight basins of similar form are so fastened together as to lie one within the other, with a small water-filled space between. Let the upper basin be per-

forated, and let the perforation be tightly fitted with a tube. According to a simple and familiar law, the water will rise in this tube to the height at which it stands in the space between the basins, and if the mouth of the tube be lower than the rim of the lower vessel and the latter be kept full by some external supply a constant stream will issue from the pipe. Such an arrangement as is here described would be a working model of an artesian basin. The construction of our model might be slightly modified, however, without essentially changing the principles involved. For the basin-shaped space we may substitute one between two superposed troughs or between two inclined boards, provided that the space is closed except along its upper edge. In either case a flow would be obtained from any aperture below the lowest point of the rim of the reservoir space. The essential principle illustrated in this simple manner is expressed by the familiar saying that "water seeks its own level."

In natural artesian districts, however, the conditions do not have the ideal simplicity of our primitive model. A number of additional factors come into play, materially complicating the problem. We

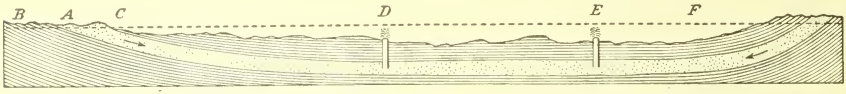

FIG. 4.—Ideal section illustrating the requisite conditions for artesian wells. (After Chamberlin.)

have now to show to what extent natural conditions are represented by our model, and in what respects the difference of actual from ideal conditions leads to modification of the simple rules of artesian flow.

Suppose a basin-like valley, underlain by a stratified series of rocks that have a basin structure, so that the form of the layers corresponds in a general way to that of the surface of the ground. Suppose that in this stratified series there lies a bed of porous material, such as a coarse, open sandstone, capable of absorbing and storing a large quantity of water, and that this porous bed is overlain and underlain by some material, such as compact clay shale, which is practically water-tight. If the upturned edges of the sandstone stratum are exposed along the slopes of the hills surrounding the valley, they will absorb a portion of the rain falling upon the hills, and, in some cases, of streams flowing over the outcrop. The porous bed will become saturated with water and constitute a great underground reservoir, from which an artesian flow may be obtained by sinking a well at some point lower than the exposed area where the bed absorbs its supply. (See figs. 4, 5, 6.)

While the conditions in the basin valley are similar to those of the simple model in the most essential respects, there are two noteworthy particulars in which the natural and the ideal conditions differ.

In our working model we have for a reservoir an open space, and the basins that form its walls are water-tight. In nature the reservoir is generally constituted by an aggregation of minute but connected pores between the grains or fragments that constitute the water-bearing bed, and the confining strata are never absolutely impervious. Both these modifications of ideal conditions have an important influence upon the flow of artesian streams.

First, the water flowing to a well through the small interstitial spaces encounters a notable amount of frictional resistance, which has the effect of retarding the flow. In order to counterbalance the consequent loss of artesian pressure and obtain a generous flow the well must be situated at a point considerably lower than the area of absorption and the depression must be increased in proportion to the distance from the source of supply.

Second, leakage through the confining strata, by diminishing artesian pressure, acts in the same unfavorable way as frictional resistance, though loss from this source is not likely to be serious if the region between the area of supply and the wells is elevated.

When, therefore, we inquire as to whether the stratigraphic conditions in a given region are favorable to the hope of obtaining artesian water we must not look for absolute impermeability in the strata confining the water beds. It is necessary only that the resistance which the water must overcome in escaping through the confining strata be large in comparison with that which it encounters in flowing through the porous stratum. In other words, the stratigraphic conditions are fulfilled when we have a relatively permeable stratum confined between strata that are relatively impermeable.

We have still to consider another difference, perhaps even more important, between theoretical and actual conditions. We have assumed up to this point the absence of any exposure of the water-bearing stratum affording opportunity for leakage lower than the mouth of the artesian wells. It is probable that this condition is

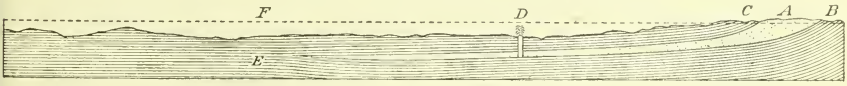

FIG. 5.—Section illustrating thinning out of a porous water-bearing bed. (After Chamberlin.)

rarely fulfilled in nature. Most valleys are drained by streams, and the gorge by which a river leaves a basin-like structural depression will cut the water-bearing stratum and expose it at a lower elevation than any point on the valley floor. An ideal artesian basin must be topographically an undrained basin, and that is an exceptional topographic form. It is probable that in the great majority of artesian districts the water-bearing stratum is cut at points lower than any of the wells.

The effect of such leakage upon the behavior of artesian water must therefore be inquired into and the reason shown why it does not destroy underground pressure in the imperfect reservoirs. It is a more or less familiar truth that moving underground water follows the path of least resistance. More definitely and specifically, we may say that the water at any given point in an artesian basin will tend to escape to the surface by the route on which it will have to do the least work in overcoming resistance. The resistances to be overcome are friction and gravitation. It is readily conceivable that in the area near a well the water can more easily overcome the gravitative resistance and rise to the surface as an artesian flow than the great frictional resistance it would encounter in passing to a distant low outcrop, even though aided by gravity.

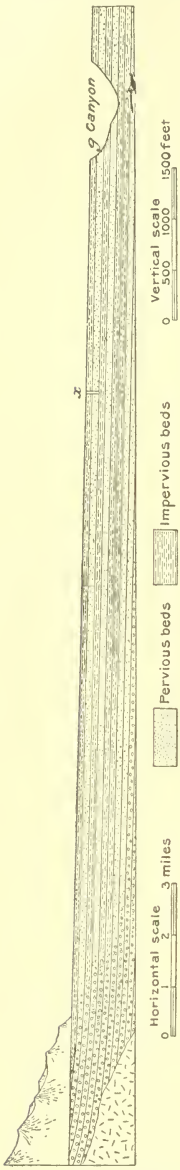

FIG. 6.—Section of an artesian slope. (After Russell.)

An illustration of the principle here involved may be cited which is familiar to the experience of everyone. In a city house furnished with a system of wate pipes, the turning on of faucets in the lower stories will not generally stop the flow from the faucets on the floors above, though it may materially diminish its force and volume.

The considerations set forth in the later paragraphs have been recognized by others,[a] and Professor Russell, from whose paper[b] the accompanying figure (fig. 6) has been taken, has proposed for the form of reservoir in question the term "artesian slope." It seems to the present writer, however, that it has not been sufficiently recognized that leakage in natural reservoirs is almost universal. When a district is examined with reference to artesian conditions, hope of obtaining artesian flows should not be abandoned on finding that the water-bearing strata were exposed at low levels, but an attempt should rather be made to estimate the degree to which the existing natural leakage will injure the artesian reservoir. It will be interesting to discuss briefly the data upon which such estimates may be based.

It is obvious, in the first place, that the danger from leakage is great in proportion as low outcrops are extensive. In the case of a basin valley, for example, it is desirable that the

[a] Chamberlin, T. C. Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1884, p. 142, fig. 17.

[b] Bull. U. S. Geol. Survey No. 199, 1902, p. 157.

gorge through which the river emerges be narrow in proportion to the size of the expanded part of the valley. Another fact, perhaps less evident, is that it is disadvantageous for the river to have cut down deeply below the general level of the valley floor. In such a case the water-bearing stratum may be very extensively exposed, and the artesian basin indeed be divided into two scoop-shaped segments with the water bed exposed along the entire edge of each. By a similar course of reasoning it may be perceived that in a given artesian district porous beds lying low down in the series will in general be less extensively exposed along the rivers than higher beds (see fig. 14, p. 65).

The effect of leakage is dependent, in the second place, on the proximity of the low-level outcrops to the place where the well is to be sunk. In the close vicinity of such outcrops the route of escape by the natural exposure of the porous stratum may offer less resistance than must be overcome in rising through the wells. At points more remote from the region of leakage, on the other hand, the loss of pressure will be much less serious, and at great distances it may become negligible. In a long synclinal valley, underlain by a water-bearing stratum having the form of a trough with open ends, the chances of obtaining an artesian flow in the central portions of the depression would generally be excellent, and loss of pressure by leakage need be apprehended only near the ends of the trough. In the case of an inclined stratum exposed along the greater portion of its lower edges the danger from leakage would probably reach a maximum. The diminution of pressure from leakage would be greatest near the low outcrops; but, on the other hand, those situated farther away would generally be at a disadvantage from being on higher ground, and the most favorable location for wells would be in an intermediate zone where conditions were somewhat balanced.

From the foregoing discussion it should be evident that the prospector for artesian water may, according to his judgment and experience, make a more or less approximate estimate of the effect of natural leakage. Each case must of course be considered for itself, yet certain rough generalizations can be made. In the central portion of a basin valley, from which a river flows by a narrow gorge and does not deeply trench the valley floor, or in the middle of a synclinal trough of great length, the loss of pressure by leakage is not likely to diminish the pressure in a fatal degree. On the other hand, a well sunk to an inclined stratum extensively exposed at a low level will generally not succeed unless the stratum is of very great extent and other conditions are favorable. The effect of leakage is, however, at best a somewhat indefinite factor in the artesian problem.

The discussion to this point has related to the structural, stratigraphic, and topographic conditions influencing artesian flows, or, in other words, to the nature of the reservoir. Of no less importance is the supply which fills this reservoir and supplies the loss from wells and springs. In order that a well shall continue to flow, the water level in the artesian reservoir must be kept higher than the mouth of the well. This supply, as has been briefly noted, is chiefly from rain falling upon the high exposures of the porous stratum and immediately absorbed. It may, however, be augmented by a considerable amount not falling directly upon the area of absorption, but flowing over it for short distances in temporary rills, and by leakage from streams that flow across the outcrop of the porous stratum. A case illustrating leakage from a stream is cited by Mr. George Otis Smith in his description of the Moxee-Atanum basin.[a] In this manner areas remote from the zone of outcrop may contribute to the artesian reservoir.

The amount of water supplied to an artesian basin depends on the area of the zone of absorption and on the amount of precipitation along that zone. The zone of absorption is necessarily higher than the flowing wells and consequently lies usually in a region of greater rainfall. Its area, however, is generally small in proportion to that of the whole artesian basin, and the amount of water that can be drawn from the underground reservoir, far from being unlimited, is very definitely determined by the average precipitation on a comparatively small area. If the amount drawn off by wells and springs exceeds the amount annually furnished by rain and snow, a diminution of artesian pressure must result. Many wells that gave a powerful stream at the beginning have ceased to flow when borings have multiplied in their vicinity. This danger of wasting the artesian supply has been recognized by the legislature of the State of Washington,[b] which has framed a wise law compelling owners to cap their wells during the rainy season (from October 1 to April 1) and to use only such amounts during that period as are necessary for domestic purposes and stock.

We may now recapitulate the necessary conditions of artesian flow, as follows:

(1) A porous stratum capable of absorbing large quantities of water and allowing it free passage.

(2) Relatively impermeable strata above and below, capable of confining most of the water under pressure.

(3) An exposure of the edge of the porous stratum where it may absorb water falling upon it, and, to some extent, that of rills and streams flowing across it.

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[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Wash.: Water-Sup. and Irr Paper No. 55, U. S. Geol. Survey, 1901, p. 56.

[b] Stat. Washington, chap. 121 (H. B. No. 203).

(4) An inclination or folding of the water-bearing stratum and a corresponding slope of the surface of the ground, so that the proposed wells may be located below the zone of supply.

(5) Absence of low-level outcrops sufficiently extensive and sufficiently near the proposed wells to cause great loss of pressure by leakage.

(6) A sufficient supply of rain water to maintain the artesian head.

DATA CONCERNING DEEP WATERS.

ARTESIAN DIVISIONS OF THE REGION.

We may now proceed to discuss, in the light of the general principles just laid down, the artesian problems for the region here considered. In this discussion we must use the facts already set forth concerning the natural conditions of the region and, further, the well records that give direct evidence regarding the occurrence and behavior of underground waters.

The facts can not be discussed for the region as a whole, since conditions vary considerably in different portions. A division can be made, however, into districts in each of which the natural conditions are fairly uniform. Those in which deep wells already exist are designated (1) the Connell-Ritzville district, (2) the Hartline district, (3) the Quincy district, and (4) the Kittitas Valley district. In the desert area traversed by Saddle Ridge there are no deep wells, but the natural conditions will be discussed separately for the portions of the desert south of and north of that prominent structural feature.

STRATIGRAPHIC CONDITIONS IN COLUMBIA PLAINS.

The stratigraphic conditions are so uniform throughout the Columbia Plains that it will be profitable to consider these conditions from the artesian standpoint before proceeding to discuss the special features obtaining in each of the districts just blocked out, all of which lie within the Columbia Plains except the Kittitas Valley, where the stratigraphy is somewhat different and must be discussed separately.

In that portion of the Columbia Plains considered in this report the Ellensburg beds are so distributed as to afford little ground for the hope that an artesian supply can be obtained from them. The obstacles to such a hope are the facts that the high outcrops receive but a very small supply of atmospheric water, and that the beds are too extensively dissected by the canyons and coulees.

If artesian water is to be obtained in this portion of the plains it must be from the basalt series or from beds of sandstone intercalated with the basalt. In discussing the artesian problem for this area, therefore, it is important to consider whether the manner in which the basalt series is built up is favorable to the storage of deep water and its conservation under pressure. The required condition, it

will be remembered, is that strata capable of containing much water and of allowing it to pass with comparative freedom shall alternate with strata that are comparatively impervious.

The lithologic character of the basalt, including its texture and the structural features of the massive flows and pyroclastic beds, and the character and extent of the materials other than basalt intercalated with the upper layers of the series, have been described in a previous section. The facts pertinent to the present purpose may be recapitulated briefly as follows: The lava series is built up mainly of a great number of massive flows with rough vesicular surfaces. The massive lava is universally cut up by joints developed in the process of cooling into columns, plates, and irregular blocks. Intercalated with the massive flows are beds of porous tuff and breccia, which, however, occur in small volume as compared with the true lavas. A few beds of acid tuff and of sandstone are interbedded with the upper layers of the series, but are very rare in the lower portion of the section.

To the hasty observer the vesicular or "honeycombed" upper portions of the basalt flows might seem well adapted for the storage of water, but a little thought will show that such an idea is largely fallacious. The vesicles of the amygdaloids are not connected, but are inclosed chambers incapable of receiving water except by slow infiltration and quite incapable of allowing its free passage. To quote the language of Chamberlin, the porosity of a water-bearing stratum should be of an "interstitial and not a vesicular kind."

But if the vesicular portions of the flows are not available for water storage there seems reason to believe that there are spaces between the lava flows, thin and irregular but extensive, that might serve as reservoirs. The surface of a freshly cooled lava flow, though level and monotonous in its broad aspects, is rough in detail. A second flood rolling upon a surface thoroughly cooled will probably not generally completely fill the inequalities of the preexisting surface. The crust forming upon the top and front of the liquid flow, broken and rolled under by its advancing motion, will often form a rough layer that does not fit closely into the minor unevenness of the cooled lava beneath. It is believed that waterways are often constituted by the spaces thus left by the failure of a more or less viscous flow to fill completely the roughnesses of the surface upon which it was poured. Though small in the beginning, these subterranean spaces may subsequently become enlarged by the solvent action of deep waters.

The ability of the porous tuff beds and breccias to absorb and contain water is evident to anyone familiar with their character, and it is believed that they probably contain the most generous supplies of water to be found in the basalt series in the region here considered.

Some of the beds of siliceous tuff and sandstone already described

are probably well fitted for water storage, but they are apparently of only local importance. They may be found a source of water in the low-lying southwestern portion of the region, but the records of wells and observations of natural sections go to show that sandy beds are so rare in the eastern and northeastern portion as to be practically negligible.

We have next to consider whether the massive basalt is capable of confining under pressure the water stored in the porous beds.

The massive compact basalt is in itself a practically impermeable rock. The universal presence, however, of crevices, due to contraction partings, has led some observers to believe that the basalt is in general incapable of confining water under pressure. With this view the writer has been led to disagree, mainly by certain facts learned from well records.

Water in the deep wells of the plains is never found in any useful quantity in the massive basalt itself, but always in softer material between the compact layers. It is known to exist under pressure sufficient to raise it 250 feet in certain localities where there is no evidence of any strata of clay or silt which could have been efficient in preventing its escape from the pervious bed. It is concluded, therefore, that the basalt does to a notable extent have the ability to confine water under pressure. The crevices in the massive rock, especially in the case of flows where the columns are small and irregular, are believed to be not only minute but generally not continuous throughout the flow, and to allow the passage of water in but comparatively small amount. At the same time it is admitted that jointed basalt is probably less efficient material for a confining stratum than clay or fine shale.

To sum up, then, it appears that the basalt series presents an alternation of strata of differing permeability favorable to the storage of artesian water, though the stratigraphic conditions are probably not so favorable as they are in a series of open sandstones alternating with beds of fine shale or clay. The water-bearing layers in the basalt series consist of acid tuffs and sandstones, thin irregular spaces between the flows, and basaltic tuffs and breccias. The massive basalt, although universally creviced, is considered to be of low permeability in comparison with these porous layers.

CONNELL-RITZVILLE DISTRICT.

By this name we may designate that portion of the wheat lands which lies south of upper Crab Creek. This area, though very extensive, is characterized by a similarity of conditions that justifies its treatment as a unit in the discussion of deep wells.

Structure.—The structure of the basalt underlying this district is

not easily made out except through a broad study of the region, because the inclination of the lava flows, as observed in the walls of the coulees, is almost imperceptible in amount, and its direction and degree can not generally be determined except by careful instrumental observations, which the writer was not able to make. The interpretation of the structure is based largely on topographic grounds. The general surface of the land east of the Northern Pacific, lying at an elevation of nearly 2,000 feet above sea level, probably coincides nearly with the original surface of the basalt, or is below that surface, which may have been largely reduced by erosion. The desert area to the west and southwest, lying at a considerably lower level, is underlain in part by Ellensburg beds, which cover the basalt to a depth of several hundred feet. The surface of the basalt is, therefore, farther below the surface of the ground in this region than in the more elevated lands to the northeast. It may therefore be inferred that the basalt underlying the Connell-Ritzville district has in general a very gentle inclination to the southwest.

Topography.—The upper portion of the basalt series in this district is trenched by a large number of coulees, having a maximum depth below the surface of about 400 feet, though when the thickness of the gravel deposits in their bottoms is considered it appears that the trenches in the bed rock have depths as great as 600 feet. The average depth of the coulees is greatest in the southwestern portion of the district, which is nearest the master streams of the Columbia Plains, the Snake and the Columbia. Far to the west the basalt is deeply cut into by Columbia River, which exposes strata many hundred feet below the top of the series.

The general intrenchment in the wheat lands has an important relation to the deep wells. It is evident that any porous strata existing in the basalt series at horizons above the general level of the neighboring canyon bottoms would be extensively exposed to leakage along the canyon walls, and that while it might at some localities carry considerable water, it could not be expected to contain it under artesian pressure.

Supply.—The writer is unable to present any information based on detailed observation in regard to a region of supply for the deep-lying porous strata under the eastern wheat lands. Study of maps and level lines shows that along the eastern boundary of Washington and in northern Idaho there is an elevated region which receives a more abundant rainfall than the district considered. Part of this region was seen by the writer in traveling by rail between Ritzville and Spokane. It is a surface of erosion with many inequalities that would probably increase its efficiency as a gathering ground. Some of the lower beds in the basalt series may be exposed there, and may

absorb a portion of the rainfall. A supply may also be furnished from the edge of the basalt formation at the base of the mountains in Idaho, though that region is so far distant that it seems doubtful whether it may be assumed that any porous beds extend continuously thence to the Ritzville region.

Well records.—The reader may gather from the facts above stated that the natural conditions, considered apart from experimental evidence, in the Connell-Ritzville district do not seem greatly to encourage the hope of obtaining artesian water. There are several factors of uncertainty in the theoretical problem, however, that make it desirable to scrutinize all the evidence obtainable from wells that have already been sunk. The appended list gives the data collected by the writer in regard to these. The list does not include by any means all the wells in the district, but it is believed that the expenditure of time necessary to make an exhaustive list would not have been justified, and that the data obtained will serve the main purposes of the examination.

A few words applying to all the data for the Columbia Plains may also be prefaced in regard to the fullness and reliability of the well records obtained. Owing to the fact that the rock penetrated is mostly basalt, not intercalated with any considerable amounts of tuffs, sandstones, or shales, it has not become customary to keep any regular records of the material through which the drill passes. There has been simply a differentiation between "rock" and "dirt," for the purpose of reckoning charges. Any more detailed information that has been gathered, therefore, has been supplied from the memory of drillers or of others interested in the wells. In regard to depth, the figures have in some cases been taken from written records, but in others from the memory of owners and drillers. It is believed, however, since most of the wells are of comparatively recent construction, that the figures given are substantially accurate.

Partial list of wells in Connell-Ritzville district, Washington.

Owner.	Location.	Depth.	Depth to surface of water.	Depth of soil, etc.	Remarks.
1. Northern Pacific R. R.	Eltopia	151	115	------	
2. Do	Lake	354	284	------	
3. J. W. Gover	Sec. 24, T. 13, R. 30	311	297	------	
4. Jas. Elgin	Sec. 33, T. 13, R. 32	323	283	[a] 84	Water at 310 feet.
5. Brayden Bros	Sec. 32, T. 13, R. 32	674	629	14	
6. M. C. Moore	Sec. 21, T. 13, R. 32	78	------	------	Supply not abundant.

[a] 80 dirt; 4 gravel.

Partial list of wells in Connell-Ritzville district, Washington—Continued.

Owner.	Location.	Depth.	Depth to surface of water.	Depth of soil, etc.	Remarks.
7. H. C. Baker	Sec. 29, T. 13, R. 33	575	551	23	
8. Northern Pacific R. R.	Connell	228	.....	[a] 6 [b] 180	
9. H. W. Brummond	Sec. 8, T. 14, R. 32	410	395	42	
10. Eugene Adams	Sec. 6, T. 14, R. 32	510	.....	.....	
11. Wm. Mittelstadt	Sec. 35, T. 15. R. 31	318	293	30	
12. Wm. Dickinson	Sec. 25, T. 15, R. 31	360	330	75	
13. Wm. Brown	Sec. 13, T. 15. R. 31	425	325	50	
14. Town	Hatton	300	7	37	Water rises.
15. Andrew Newland	Sec. 35, T. 16, R. 31	430	380	50	
16. Cunningham	Sec. 10, T. 16, R. 32	255	150		In bottom of coulee.
17. C. S. Hedrick	Sec. 34, T. 16, R. 32	300	250	40	
18. Merrill	Below Lind	.....	320	.....	
19. McMannaman and Van Marten	East of Lind	130	100	.....	
20. Northern Pacific R. R.	Lind	225	32	25	Water rose to top of basalt.
21. Town	do	286	30	10	
22. Adam Buehler	Sec. 15, T. 18, R. 33	363	328	14	
23. Louis Pflugard	Sec. 14, T. 18, R. 33	318	298	35	
24. Fred Scheel	Sec. 8, T. 18, R. 36	297	172	25	
25. Chas. Lakes	Sec. 32, T. 19, R. 33	300	250	40	
26.	Sec. 30, T. 19, R. 33	110	20	20	In coulee.
27. Dan Scott	Sec. 35, T. 19, R. 34	358	258	50	
28. Henry Myers	Sec. 32, T. 19, R. 34	350	250	70	
29. A. Johanson	Sec. 32, T. 19, R. 34	250	235	70	
30. City of Ritzville	Sec 23, T. 19, R. 35	360	200	50	Elevation, 1890.
31. J. W. Johnson	Ritzville	180	.....	46	
32. Scott	6 miles west of Ritzville.	358	270	.....	
33. Odessa Mill	Sec. 5, T. 21, R. 33	137	40	23	
34.	Sec. 26, T. 21, R. 30	211	206	31	Water in red "honeycomb rock;" lateral flow washed away drillings.

[a] Soil. [b] Gravel.

A few general statements may be deduced from the list concerning these wells.

In comparing depths, allowance must be made for the fact that some wells are sunk from the high plateau surface of the wheat lands, while others are situated in the coulees, from 50 to 400 feet below the general upland levels. Comparing the average depths of wells in the uplands, we obtain the following results: For the thirteenth and fourteenth rows of townships, 406 feet; for the fifteenth and sixteenth, 367 feet; for the eighteenth and nineteenth, 327 feet. There is thus, in general, a slight increase in average depth from north to south. The explanation of this fact is probably to be found in the greater depth of the coulees in the southern portion of the district, which is near the master stream of the region, where the ancient streams were most deeply intrenched.

The figures in regard to depth of soil have interest, though without direct bearing on water-supply problems. The soil is seen to be in general very deep, apparently attaining its greatest depth on the brows of slopes, where the conditions are most favorable for wind accumulation. Some indication of the amount of hardpan was gathered from descriptions of wells. This material seems to be thickest in the neighborhood of Ritzville. The depth of gravel in certain of the coulee bottoms is also given by the well records.

In regard to the character of the rock in which water is found, the information is, of course, not very definite, since it is based upon the relative ease with which the material is penetrated by the drill and by the appearance of small fragments brought up by the sand pump. No case is recorded, however, where the water-bearing stratum is sandstone, a material that could hardly fail to be recognized. The water-bearing material is always softer than the massive rock, and is usually described as "honeycomb," less seldom as "brown gravel," or "bowlder formation," etc., but no true waterworn gravels were seen in any of the natural exposures of the basaltic series. The testimony all seems to indicate that the deep water is generally found in porous or fragmental basalt.

The third column, headed "depth to water surface," contains data that are of the highest interest, because they give the most positive evidence obtainable in regard to artesian conditions. Drilling is usually stopped almost immediately upon obtaining a good supply of water, and any considerable difference between the corresponding figures in the third and fourth columns usually indicates that the water has risen from the water-bearing stratum. Such a rise indicates that the underground water is under pressure and, therefore, in the general sense of the word, artesian.

This artesian rise of water varies in different portions of the region. To the south it attains 70 feet in the railroad well at Lake. But

nowhere in the southern portion of the district is the rise considerable enough to give much hope of obtaining artesian flows.

The most encouraging information was obtained in the vicinity of Lind, where the town well has water standing within 30 feet of the surface, having risen some 250 feet by artesian pressure. Another well was recently bored there for the Northern Pacific Railway Company to a depth of 225 feet. The water was in a porous rock which extended from within 60 feet of the surface to the bottom, where the principal flow was obtained. The water rose 200 feet, to the top of bed rock. Another well in Lind Coulee, a short distance below the town, tapped water which quickly rose to within 3 feet of the surface, but sank afterwards some 20 feet. The latter fact is accounted for on the supposition that the loose surface material was packed and rendered partly impervious by the friction of the drill rope, but became porous again after the water had washed the fine material from the sides of the bore. A consideration of this case should enforce the important lesson that the failure of the water to reach the surface may often be due, not to lack of sufficient pressure, but to leakage through porous material forming the sides of the upper portion of the well. There seems to be very good reason for the hope that artesian water, at least in small quantity, might be obtained at Lind by properly casing the wells.

Northward, in the neighborhood of Ritzville, a rise generally occurs. The water seems to lie at an average depth of about 300 feet below the upland surface, from which depth it is forced up by artesian pressure from 50 to 100 feet, resting from 250 to 200 feet below the general plateau level. In the town well at Ritzville the water surface lies less than 100 feet below the nearest point in the coulee bottom. In the mill well at Odessa the water has risen within 40 feet of the surface, or within 17 feet of the top of the basalt. In a well 110 feet deep in sec. 30, T. 19, R. 33, the water comes within 20 feet of the mouth, and probably escapes by leakage. Attention is called to the importance of the fact that a rise of water in the wells is very general throughout the region. This matter will receive further discussion in the sequel.

Another phenomenon indicating the distant source of the water is a lateral flow noted in one or two cases and shown by the washing away of the drillings.

In regard to the quality and quantity of the water a few general statements may be made. Nearly all of the deep wells, so far as known, yield a supply sufficient to meet all demands for present uses, and one that remains constant throughout the year. The largest supply known to have been furnished was given by the Ritzville city well, which was guaranteed by the contractors to furnish 5,000

gallons an hour and which has, in fact, furnished a stream of that volume for twenty-four hours without perceptible lowering. The quality of the deep waters is generally excellent and far superior to that of surface wells or springs, the underground water being soft and of good flavor. Regarding temperature, the data gathered were too meager to form the basis of discussion, but there is as usual a general increase of temperature with depth.

HARTLINE DISTRICT.

The Hartline district is defined as comprising the western part of the valley traversed by the branch line to Coulee City, in which lie the villages of Parnell, Wilbur, and Hartline.

Structure.—The layers of basalt beneath Hartline Valley have been gently flexed into a synclinal or trough-like form, limited on the south by a low, gently arching swell and on the north by a plateau. The western end of the valley meets the Grand Coulee almost at its own level and is faced by the moderate slope up which the road to the plateau beyond is laid. This slope is in a measure conformable with the structure of the basalt underlying it, the layers of basalt being turned up in such a way as to close up the western end of the syncline. The eastern end of the Hartline trough was not visited, but observations from a moving train give reason to believe that its bottom rises in that direction and that the syncline dies out upon the high plateau land. The Hartline district therefore seems to lie in a spoon-like structural depression, a fact which in itself favors the hope of obtaining artesian water.

Topography.—The greatest imperfection in the Hartline basin is its deep dissection by the Grand Coulee. The northern portion of the coulee lies nearly 400 feet, and the southern portion below the old cataract nearly 800 feet, lower than the floor of the valley at Hartline. The close proximity of a chasm so deep must have a very considerable effect in reducing pressure in the basin by affording opportunities for leakage from the water-bearing strata.

Supply.—In regard to the source of the underground water of the district, the remarks on that matter in the description of the southern wheat lands apply equally in this place. The principal area of absorption probably lies on the high land to the east, but the writer can supply no data based on actual observation.

Well records.—Theoretical consideration of the conditions in Hartline Valley do not, on the whole, indicate very decisively the existence of a true artesian basin, and the evidence of the wells, as in the case of the southern wheat lands, will be useful in aiding a judgment on the possibility of obtaining surface flows. Most of the data exhibited in the following table have been supplied by Mr. J. A. Wilburn, of Hartline, one of the principal drillers of the district.

Partial list of wells in the Hartline district, Washington.

Owner.	Locality.	Depth.	Depth to water surface.	Thickness of soil.	Remarks.
		Feet.	*Feet.*	*Feet.*	
33. Wasapa	Sec. 14, T. 24, R. 29	400	------	------	No water.
34. H. Childs	Sec. 19, T. 24, R. 30	203	173	16	
35. Tom Elder	Sec. 18, T. 24, R. 30	147	115	28	
36. Do	Sec. 12, T. 24, R. 30	168	------	------	
37. Rodgers	Sec. 7, T. 24, R. 30	168	138	22	Water in a crevice.
38. J. Harris	Sec. 4, T. 24, R. 30	210	196	22	
39. Sinclair Bros	Sec. 29, T. 25. R. 30	137	83	20	
40. Do	Sec. 33, T. 25, R. 30	293	193	13	
41. Jim Hill	Sec. 6, T. 25, R. 30	242	42	32	
42. A. J. Burke	Sec. 25, T. 25, R. 29	116	65	45	
43. John McDonald	Sec. 24, T. 25, R. 29	184	40	28	Do.
44 Buckhannon	Sec. 11, T. 25, R. 29	173	40	16	

The water is said by Mr. Wilburn to occur generally in "brown gravel," though it is more probable that the material thus designated is fragmental or scoriaceous basalt rather than true alluvial gravel. In two cases, however, the water was found in a crevice, which may have been either a joint opening or a space between two flows, formed in the manner described on page 68.

The figures in the third column are of especial interest. In the last 4 wells of the list the water has risen to within short distances of the surface, varying from 40 to 65 feet. In the Hill well it is within 10 feet of the top of the basalt. In the other wells on higher ground the water has generally risen, but the pressure has not been sufficient to lift the water as near the top as in the other cases. The general rise of water indicates considerable underground pressure, and gives reason to hope that artesian flows might be obtained from the lower wells if they were properly cased.

QUINCY DISTRICT.

This district comprises the northwest quarter of what has been termed the desert, upon the northern border of which lies the small hamlet of Quincy, where 4 drilled wells have been sunk.

Structure.—Quincy lies in a structural depression, though the fact is not evident at once, since the basin is a broad one and has been greatly marred by erosion. Just north of the village a structural slope rises to the ridge overlooking Willow Springs, and 18 miles to the south a low arch forms the opposite side of the east-west trough.

Far to the east the basalt rises to the wheat-lands plateau, and to the west the lava flows are turned up, forming the long gentle slope of Table Mountain.

Topography.—If, however, only the upper portion of the basalt series is considered, it appears that the Quincy basin is merely a trough, open at both ends. The Grand Coulee and its southern continuation have cut down at least 150 feet, and the Columbia 800 feet, below the top of the basalt series. The proximity of the river gorge is, of course, disadvantageous.

Supply.—Only a small amount of water can be supplied to the upper strata of the basalt series from the ridges north and south of the Quincy basin, on which the rainfall is extremely light. There may be a slight contribution from middle Crab Creek, though there is no positive evidence of the fact. The deeper-lying porous beds may draw a supply from the far-distant elevated land east of the Ritzville region, but it is doubtful whether there are any such beds continuous for so great distances.

Well records.—On the whole, the uncertainty of supply, combined with the deep dissection of the basin, discourages the hope of obtaining surface flows, at least any of moderate depth, in the Quincy district. The well records, of which a list follows, confirm these inferences:

List of wells in the Quincy district, Washington.

Owner.	Location.	Total depth.	Depth to water.	Depth of soil, etc.
		Feet.	*Feet.*	*Feet.*
	Sec. 12, T. 20, R. 24	194	190	40
	Do	194	190	40
	Do	260	190	40
Marble	Sec. 6, T. 20, R. 24	330	190	22

The water is found in soft material that seems to be basaltic tuff. Two soft layers were penetrated in the Marble well and one in the wells in the town itself.

AREAS WITHOUT DEEP WELLS.

Desert near lower Crab Creek.—In the region between Saddle Mountain and the next ridge north the conditions are very similar to those that obtain in the Quincy district. Between these two anticlinal ridges is a synclinal trough, rising in a general way toward the wheat lands at the east and closed at the west by the structural slope of Table Mountain.

Topographically this area is generally lower than the Quincy district. It is bordered on the west by Columbia Canyon, which here is not very deep, and is trenched by Crab Creek coulee in its central and southern portions.

The conditions of supply for this desert section seem to be unfavorable, for it is bordered on all sides by arid country. A large portion of the front of Saddle Mountain is a cliff, along which no water could be furnished to the porous beds underlying the region north of it.

The conclusion reached by consideration of natural conditions and by comparison with other districts is that, while water could probably be obtained from deep wells sunk down as far as the level of Crab Creek, there would be no reasonable hope of obtaining artesian flows in this portion of the desert.

Bench south of Saddle Mountain.—This broad unwatered area is underlain by Ellensburg beds, which in turn lie upon basalt, with interbedded acidic tuff and sandstone. The base of the Ellensburg and portions of the upper layers in the basalt series are exposed along the slope of Saddle Mountain and far to the east. The district is on the marginal portion of a great structural basin, in which lie Pasco and the Rattlesnake Desert.

The strata underlying the broad expanse of this bench are so extensively dissected by the Columbia that there seems nothing to warrant expectation of their containing water under sufficient pressure to rise to the surface. There is little doubt, however, that water could be obtained in this district from wells of moderate depth. The abundant flow of cool water from Harrison Springs appears to indicate the presence of a saturated bed at no very great distance below the surface, but the water in this layer, finding such free outlet at the springs, can not be under sufficient pressure to raise it very far above their level.

The terrace land near the head of White Bluffs and across the Columbia is lower, and therefore more favorably situated. It has not been sufficiently examined by the writer, however, to entitle him to a very definite opinion in regard to the prospects of artesian water. The arid character of the surrounding country and its dissection by Columbia, Yakima, and Snake rivers are unfavorable features.

Two experimental borings have been made in this region. One is at Pasco, where a well has been sunk and cased to a depth of about 400 feet in sandstone without obtaining a flow. The second is on the right bank of the Columbia, below Craig's ranch, where a boring 400 feet deep has been made without any successful result. This hole had been abandoned at last accounts, owing to the loss of the drilling tools. Neither of the borings described reached basalt, and neither

seems to furnish conclusive evidence that artesian water could not be obtained in the low arid region south of the area examined in this reconnaissance.

KITTITAS VALLEY.

Stratigraphy.—Sections of the Ellensburg beds, wherever studied, have shown an alternation of layers varying in coarseness, which is favorable to the conservation of artesian water under pressure. In the White Bluff section such alternation has been noted. In Kittitas Valley the Ellensburg beds exposed in numerous sections are found to consist of gravels, sandstones, and fine silty stuff in frequent alternation. The lowermost part of the section, according to Mr. George Otis Smith, contains a large proportion of gravel, and is therefore especially adapted to store a large quantity of water, which would be confined between the basalt below and the silty materials above. The basal portion of the Ellensburg in Kittitas Valley therefore seems well fitted by its lithologic character to serve as an artesian reservoir.

The Ellensburg beds underlie the floor of Kittitas Valley to a depth of several hundred feet, possibly a thousand feet or more. In the Moxee basin artesian water is found, at depths generally ranging between 600 and 1,000 feet, near the base of the Ellensburg formation. It is probable that if artesian water is to be found in Kittitas Valley it will probably be in the same stratigraphic position and at about the same depths.

Structure.—The structure of Kittitas Valley may best be comprehended by reference to the map and structure sections. It will be seen that the dips on all sides of the valley converge toward its center, and that the basin structure is complete though not simple. The form of the basin may be roughly reproduced by taking a sheet of paper and pinching up a wrinkle in one end, when a scoop that will hold water will be formed. The wrinkle is represented by the anticlinal ridge between Clerf Springs and the main southeastern continuation of Kittitas Valley, known as the "Badger Pocket."

Topography.—The structural conditions here seem to fulfill the artesian requirements almost ideally. The cross section of the valley shown in Pl. II might well serve as a diagram of a typical basin. Like nearly all structural basins, however, its rim is cut by a stream which exposes the edges of the water-bearing series from top to bottom, and we have to consider to what extent the pressure is thus diminished by leakage. General considerations already stated in the theoretical discussion of artesian conditions lead to the belief that the exposures in the narrow canyons by which the river enters and leaves the broad valley are not extensive enough to cause great loss of pres-

sure. Another consideration urged by Mr. Smith [a] may also be noted here.

The Moxee artesian basin is cut by Yakima River in exactly the same manner as the Kittitas basin. Mr. Smith considers that leakage at the low outcrops in the Yakima gap has been to a large extent prevented by the action of mountain-making pressure, which has produced intense folding along the southern side of the Atanum-Moxee valley, and has incidentally compacted and indurated the beds of sandstones. Mr. Smith cites evidence of similar intense dynamic action at the head of Yakima Canyon, and suggests that leakage at this point may be largely prevented in the manner indicated. While the present writer is hardly inclined to concede to this agency the degree of efficiency that Mr. Smith ascribes to it, he believes that it may, by increasing the resistance to leakage, help to maintain pressure in the water-bearing strata.

Supply.—The supply of water for the reservoir strata in this case must be imbibed along the outcrop of the base of the Ellensburg on the surrounding hills. This supply will not consist solely, however, of rain water falling on the slopes and immediately absorbed, but may be largely augmented by leakage from the bottoms of streams that flow across the upturned edges of the sandstones.

Probably the greater portion of the water that finds its way into the Ellensburg sandstones of this valley comes from the slopes of Table Mountain to the north and northeast. The outcrop along this slope is probably washed by more rain than falls in other portions of the valley, and is crossed by a great number of streams which can hardly fail to make some contribution to the underground supply. On the whole a large amount of water must enter the Ellensburg sandstones along its very extensive high outcrops, and should be sufficient to supply many flowing wells.

Well records.—As may be gathered from the preceding paragraphs, the conditions of structure, stratigraphy, topography, and supply all seem to favor the hope of obtaining artesian water in this valley. But to many practical persons it may seem that the conclusions arrived at by theoretical deduction are less valid than evidence derived by actual experiment. Some attempts have been made to obtain artesian water in this district, without any positive success. It will be well to review the results of well digging in the Ellensburg sandstones, and to try to judge the value of the evidence derived in this manner.

Information was obtained from Mr. Joseph Preece of several hand-dug and drilled wells in the southeastern part of the valley. They penetrate the Ellensburg sandstones to slight depths only, and prob-

[a] Smith, G. O., Geology and water resources of a portion of Yakima County, Wash.: Water-Sup. and Irr. Paper No. 55, U. S. Geol. Survey, 1901, p. 41.

ably do not approach the base of the series by hundreds of feet. On the Stoney ranch, 6 miles southeast of the Preece ranch, there is a well 150 feet deep in which the water rose 25 feet after the water-bearing layer was first struck.

In an old well 45 feet deep on the Preece ranch, dug by the owner, the water rapidly rose 10 feet from the bottom, though the sides had remained perfectly dry until the water-bearing stratum was struck. The water was soft, noticeably warm, and maintained a constant temperature throughout the year, so that it would "steam" in the cold air of winter. The warmth of the water at so moderate a depth indicates its derivation from a distant source, and its sudden rise from the water-bearing layer shows it to be under pressure. In short, the water is artesian in the broad sense of the word. No attempt was made to case the wells or to determine by a test how far the water would rise in an open tube connected with the porous stratum if it were prevented from escaping except by way of the tube.

The Sanders well, north of Ellensburg, which is the only deep boring ever sunk in Kittitas Valley, is said to have reached basalt after passing through 700 feet of sandstone and clay. The tools were lost at that depth and the well was abandoned with the water standing 40 feet below the surface. The negative result of this experimental boring has been pretty generally accepted as demonstrating the futility of any further attempts to obtain artesian water in Kittitas Valley.[a]

Before we accept this discouraging view, however, we should ascertain whether the record is trustworthy and whether the well was properly cased. On neither point has the writer been able to obtain satisfactory information. There is reason to believe, however, that the driller was both inexperienced and incompetent, and altogether unfit to be intrusted with the important task of boring an experimental well. The evidence afforded by the Sanders well, therefore, should by no means be accepted as conclusive.

But we are not without positive evidence in a strong degree contradictory to that just considered in the phenomena at the Clerf Spring. Clerf Spring is, in effect, a natural flowing artesian well. A well was bored near the spring in 1900 in the hope of augmenting the supply obtained from the spring, with the result that water was obtained at a depth of 40 feet below the surface of the basalt, which rose to the surface in an open pipe. The drilling at this point was made with poor machinery and by an incompetent driller. The hole has been abandoned and allowed to cave in about the top, though it is probable

[a] Russell, I. C., Geological reconnaissance in central Washington: Bull. U. S. Geol. Survey No. 108, 1893, p. 69.

that a more generous supply could be obtained by going deeper. The well as it stands gives no new evidence, however, beyond that afforded by the spring, which demonstrates the existence beneath this locality of underground water under pressure sufficient to force it up to a level considerably higher than that of the floor of the valley.

After a consideration from a theoretical standpoint of the natural conditions obtaining in the district and an examination of the evidence afforded by existing wells, the writer is confident that artesian flows would be obtained at most points in the valley floor lying below the level of Clerf Spring by properly constructed wells reaching to the base of the Ellensburg series. Anyone intending to prospect for an artesian supply should, however, intrust the task of boring to a driller of known skill, experience, and integrity.

If the possibility of tapping an artesian reservoir be admitted, however, it still remains open to question whether the expense of deep borings would be justified, in view of the prospective construction of high ditches from the upper Yakima River. When the proposed ditches shall have been built they may efficiently supply all the area above and beyond the present irrigation ditches that could be benefited by an artesian supply. It may, however, be considered desirable to have a town water supply from a deep source free from the danger of polution, which is never entirely absent from surface streams.

SUGGESTIONS IN REGARD TO DEEP WELLS.

A few suggestions may appropriately be given here to guide drillers and others interested in deep wells, and especially to direct intelligent prospecting for artesian water.

TESTING ARTESIAN PRESSURE.

It is remarkable, in view of the encouraging indications of underground pressure afforded by certain wells in the vicinity of Hartline and of Lind, that no tests whatever have been made in the wheat lands to determine definitely whether artesian flows might be obtained from properly cased wells. A few such tests, intelligently made, might show, at no great expense, the existence of an important natural resource in the region. The development of flowing artesian water would not only benefit the landowners, but the drillers as well, for it would enhance the demand of their services. It would therefore be to the interest of drillers to provide themselves with the simple apparatus necessary and to test the underground pressure wherever there appears reasonable hope of obtaining a surface flow.

A general description of the kinds of apparatus used and of the methods and principles involved in such tests is given in the following extract from Chamberlin's admirable essay on artesian wells:[a]

Control of flow.—It is clear, upon consideration, that perfect control may be obtained by putting down a tube to the densest portion of the upper confining bed, if, by some device, the space surrounding it may be closed up so that no water can rise outside of the tube. Formerly this was done by a very simple and ingenious device known as the seed bag (fig. 7). A long, stout leather bag is made in the form of a cylinder, open at both ends, and just the size of the well bore. This is slipped on the lower end of the pipe, and the bottom of the bag securely fastened about the tube by wrapping with marline. A thimble just above the tie will aid in preventing slipping. It is then filled with dried flaxseed, and the upper end likewise closed around the tube. When thus adjusted it is lowered into the well to the point determined upon and supported there until the seeds swell by absorbing water. This enlarges the bag so as to fit the bore tightly and shut off all water from rising outside the pipe, and so all is compelled to ascend through the tube to the surface, or at least as high as the pressure is competent to force it.

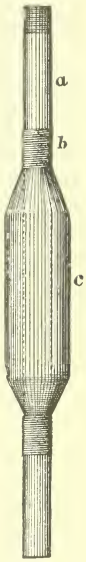

FIG. 7.—Seed bag. *a*, Delivery tube, leading to the surface of the well, and terminating below the seed bag; *c*, a leather bag filled with dry flaxseed; *b*, marline wrappings to secure the end of the seed bag. (After Chamberlin.)

A better and more convenient, but more expensive, packing takes advantage of the expansion of rubber disks when pressed together, instead of the swelling of flaxseed. A series of thick, washer-like rings of rubber are fitted about a section of pipe, so adjusted between iron disks that, after being put down, they can be screwed together and so caused to expand laterally and completely fill the bore.

The construction of the parts and their adjustment are sufficiently indicated in the accompanying figures, which illustrate one of the forms in use.

In a form employed in the oil regions the expansion of the rubber disks, or of a single cylindrical one, is accomplished by pressing a conical hollow wedge between the pipe and the rings, thus forcing them out against the walls of the well.

In this case the packing is supported by a perforated tube—an "anchor"—reaching to the bottom of the well. As the packing in artesian wells is often located near the top, the necessity for support from below excludes this form in most cases.

Detection of flow.—It has been remarked above that the water may rise from the bottom to some higher portion of the well and there find escape by passing off laterally through the upper strata. In the absence of control the water does not always rise and overflow. It is a matter of some practical moment, therefore, to know when a stream is struck which may yield a flow at the surface when put under proper control. (1) Such a stream usually discovers itself by a rise of water in the well, but this is not always the case. (2) Some

[a] Chamberlain, T. C., Requisite and qualifying conditions of artesian wells: Fifth Ann. Rept. U. S. Geol. Survey, 1885, pp. 131–172.

influence on the action of the drill is liable to be felt, which may arouse suspicion. (3) In any instance of a strong flow the drillings are apt to be carried away, so that when the sand pump fails to bring these up, or brings only coarser material, there is good reason to believe that a stream has been struck, and the proper tests should be made. In enterprises that do not require a voluminous flow, tests should usually be made when such indications appear.

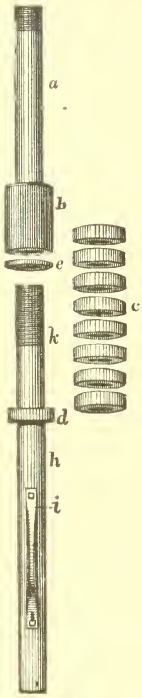

FIG. 8.—Rubber packing, shown apart. *a*, Section of delivery tube, extending to the surface; *b*, a large thimble into which *k* screws; *e*, an iron washer; *c*, a set of rubber disks fitting on *k*, between *b* and *d*: *k*, a section of pipe on which is turned a long screw fitting in the thimble *b*; *d*, a disk forming the head of the screw *k*; *h*, a section of pipe extending about 2 feet below the packing; *i*, a spring to press against the walls and hold the pipe *h* while the section *a* and thimble *b* are screwed upon *k*. (After Chamberlin.)

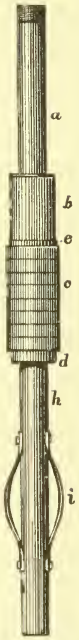

FIG. 9.—Rubber packing, shown screwed together as it is in the well. (After Chamberlin.)

It is ordinarily desirable to test the capacity of any stratum which gives any of these or other indications, before sinking to a lower one. It is advisable to make provision in the contract for such tests, since it is not always to the interest of the driller, once his machinery is set up and well at work, to stop at the more limited depth. The capabilities of the flow may be tested by the use of a tube and seed bag, or by rubber packing, as explained above.

Negative and false tests.—It is possible, in perfect honesty, to make both a negative and a false test. Suppose the two porous beds, *A* and *B* (fig. 10), separated by an impervious layer, are traversed and the testing of the first has been neglected, either because it failed to give encouraging indications or for other reasons. It is now desired to test these. Suppose the seed bag or rubber packing be placed above the upper one. Now, if both bear a water

level equally high, the test will be fairly made and the result will indicate their combined capacity, or if both heads are at least as high as the surface at the well the test may be accepted. But suppose that the bed *A* has been cut into by erosion, or been reached by crevices, or is otherwise defective, while the other, *B*, remains intact and bears an elevated fountain head. Under these conditions the water may flow from *B* through the bore into *A* and escape laterally through it, as illustrated in the figure. Now, in this case the result may be either simply negative or positively false and misleading. If the lateral leakage through the stratum *A* effectually disposed of the flow from *B* and there was no leakage in the upper portion of the well, the water in the test tube would stand during the test at essentially the same height as before, and the result would be negative, merely failing to indicate a possibility that really existed. If, on the other hand, there was lateral leakage through the upper strata as well as through *A*, neither alone being quite competent to dispose of the flow from *B*, then the introduction of the test pipe would cut off the upper leakage, leaving the bed *A* unable to dispose of the entire flow. In this case there would be a rise of water in the tube, and possibly a flow. The mischievousness of a test of this sort lies in the fact that it appears to be a true test, while in reality it is false and misleading. The true test in this case can only be made by placing the packing between the porous beds *A* and *B*.

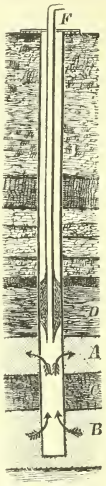

FIG. 10.—Section of well illustrating a negative test.

FIG. 11.—Section of well illustrating a partial and misleading test.

2. Take another instance where two porous beds, as *A* and *B* (fig. 11), have been traversed. Let the packing be placed between these. Then (1), if *A* equals *B* in productive capacity, water will stand at the same height within and without the test pipe if there is no leakage in the upper beds. (2) If the failure to flow was due to such leakage, then a flow will result from *B*, but the additional flow which might be secured from *A* is lost (see figure). (3) If *A* has a greater head than *B*, and if there is no loss above, the water in the test pipe will actually be lower than that outside, as illustrated in fig. 12. This may be said to be an inverted test, and is less misleading than the false and negative tests, since it plainly indicates an error of manipulation. I have known of such a case of reduced head as the result of an attempted test. (4) If, however, there is in this case considerable lateral waste in the upper strata, the valuable flow from *A* will be lost, just as before the test was made, while *B* may give a rise in the tube, or even a flow, which would foster the impression that a fair test had been made, while in reality the greater flow has been lost. (5) If *A* gives a feebler flow than *B*, but has an equal head, the test will fail of being completely satisfactory only in excluding the feebler flow from *A*. (6) If, however, *A* has a lower head and is a possible means of escape

FIG. 12.—Section of well illustrating inverted test.

for the flowage from *B*, then the packing has been placed at the right point and the test gives the best results.

3. In still another case let *A* and *B* represent porous beds (fig. 13), the lower of which is so conditioned as to drain the upper one by virtue of a lower outcrop in the manner previously explained and illustrated. (1) If the drainage loss below is not complete, and if the packing is placed above *A*, as shown in fig. 13, *I*, the result will be negative if there is no leakage in the upper strata. (2) Should there be considerable loss there it will be cut off by the tube and packing, and some rise in the tube will be the result in most cases. In either instance the result is misleading, particularly in the last, because the small rise of the water is apt to allay any suspicion as to the effectiveness of the test. The real fact, however, remains that the flow from the productive stratum is mainly lost below. (3) Suppose that the packing is located between *A* and *B*, as in fig. 13, *II*, it will then shut off the flow from *A*, while that in B, because of a lower outlet, will fail to flow. Now, if there is opportunity for lateral leakage in the upper strata the water from *A* will rise in the well outside of the test pipe and pass off into these open upper beds. (4) But if no such opportunity is afforded it may rise to the surface and overflow outside of the test pipe, while the water within the test pipe will probably be found to be lower than before the test was made.

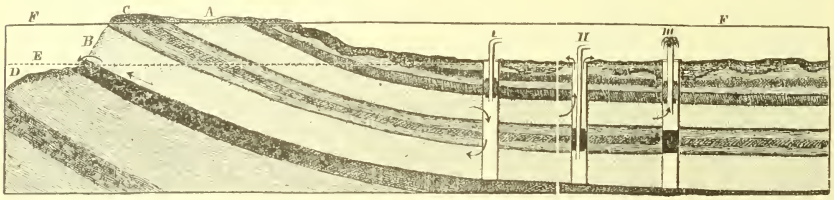

FIG. 13.—Section of strata and three wells, showing one correct and two erroneous tests.

The proper method of testing wells known or suspected to present these conditions is to sink a simple bag of seed or other obstruction to a point in the impervious stratum between *A* and *B*, which, when it tightens in its place, will shut off the flow below. Then a tube with packing sunk to a point above *A* will effectually cut off all leakage in the upper strata and the full capacity of the water bed *A* will be tested.

These examples, while not exhaustive of possible cases, illustrate the nature of defective tests and the deceptive conclusions liable to be drawn from them. The remedy is manifest. Test each water-bearing stratum as it is encountered, or else vary the final tests so as effectually to exclude all liabilities to error.

Some comment may be made on the special application of these directions in this region. In Kittitas Valley the strata encountered in the downward progress of the drill outcrop along the neighboring hill slopes at successively higher elevations, so that there does not seem to be much danger of leakage from a water-bearing stratum to the one beneath, and a plug inserted just above the highest strong flow should be sufficient. In the wheat lands, where conditions are less thoroughly understood, more care should be taken to make the tests exhaustive.

It has been noted that in wells sunk from the plateau levels of the wheat lands water is generally found at about the same depth as in the bottoms of the neighboring coulees. An artesian flow could

hardly be expected at a less depth, for the extensively dissected upper strata would be too leaky to hold water under pressure. Wells on high ground, therefore, should be sunk lower than the bottom of any neighboring coulee and the test plug inserted below all porous layers that are exposed in the coulee walls. In wells sunk in canyon bottoms it would perhaps answer in most cases to insert the plug in the first layer of compact basalt below the loose and porous surface material.

By way of summarizing this brief consideration of artesian tests it is desired to state emphatically the following important points:

(1) The fact that the water does not overflow from an uncased well does not prove that an artesian flow might not be developed under proper conditions.

(2) A well in which water rises appreciably is worthy of being exhaustively tested, unless the nonexistence of artesian conditions in its neighborhood has been proved, and the tests should be carried out with an understanding of the principles that govern artesian flow.

(3) It is unnecessarily wasteful to case a well before it has been tested. The preliminary tests may be made with inexpensive apparatus, thus saving the heavy expense of casing until it is known to be justifiable.

DEPTH OF EXPERIMENTAL BORINGS.

It is a question of some moment to what depth it is proper to carry experimental borings. An idea is widely prevalent that the chances of obtaining artesian water increase with the depth of the well, and even that artesian water may be obtained at any place if the well goes deep enough. This notion has a certain basis in the fact that deeper strata are less liable to be tapped by erosion than higher ones. Under certain conditions, however, which are illustrated in fig. 14, the deeper strata may be less likely to yield a flow than those above.

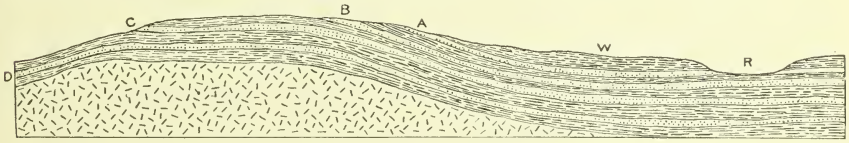

FIG. 14.—Ideal section showing relative probability of obtaining artesian flow at various depths. The stratum A is tapped by the river at R, while C and D are unfavorably situated for receiving a supply. B is capable of imbibing a good supply along its upper edge, and is not cut by the river, so that it is likely to yield a flow from a well sunk at W.

Many drillers in the wheat lands have thought that it would be worth while to sink wells to a depth of from 1,000 to 1,500 feet, in order to reach below the strata that are extensively exposed in the river canyons. Such a belief should not be adopted hastily. These deep strata would probably be less exposed to leakage, although the

writer is not sufficiently acquainted with the region to the east to speak positively, but it is doubtful whether they are favorably exposed to take in a supply available in the wheat lands. The doubt existing on this point in the present state of our knowledge should be frankly faced by anyone who contemplates putting down a very deep well. Before any such costly experiments are made some of the more favorably situated wells of the present moderate depths should be thoroughly tested. In wells to be sunk in the future each water-bearing layer should be tested as soon as reached, and if a satisfactory flow is developed at any point the owner should rest satisfied and not tempt fortune by continuing to greater depths.

CASING NONFLOWING WELLS.

If upon test a flow be developed, the well should be cased down to the point at which it is found that the packing is most advantageously located. But it does not seem wise or economical to confine casing to those wells that develop a surface flow. Suppose a well in which the underground pressure is sufficient to force the water in an open tube, inserted with a tight joint above the porous water-bearing layer, to within 50 feet of the surface, but that in its rise through the uncased well it meets a leaky, porous bed through which it escapes at 100 feet from the surface. In such a case as this the windmill or other pumping engine must raise the water 100 feet, when, if the underground pressure were fully conserved, the water need be lifted only half that distance. There is a clear waste of 50 per cent of the power, for, as is evident to all who are acquainted with the elementary principles of mechanics, a pump capable of lifting 1,000 gallons per hour through a vertical distance of 100 feet could lift 2,000 gallons per hour through half that height. The comparatively slight expense of packing the lower end of the pipe might in many cases be repaid time and time again by the saving in power where power is a source of considerable expenditure, or by the increased yield of water where all the water developed can be used to advantage.

Two qualifying phrases in the last sentence require some further explanation. In the vast majority of the deep wells now existing the pumping engines are windmills, and the cost of power is confined to the small annual expenditure for repairs, oil, etc., plus the ordinary wear and tear on the machine. Moreover, the amount of water furnished by a single mill is usually sufficient for all farm uses. Under such circumstances as these, where the running expenses are almost nothing and the supply meets all demands, there seems to be little inducement to make even a small outlay for packing the well pipe.

Where, however, a large and constant supply, such as is required to furnish a town water system, is demanded, a gasoline or steam pump is generally used. The necessary fuel is then a constant

source of expense, and, consequently, a possible saving of power, such as may be accomplished by packing, is worthy of careful consideration.

In the second place, if the rancher were able to use economically a large quantity of water it would be desirable for him to draw from his well the greatest amount that his windmill could supply under the most favorable conditions. It seems to the writer that such a use for the surplus above what is needed for ordinary farm uses is to be found in the irrigation of fruits and vegetables. While in the region east of the Columbia the conditions are such that horticulture will probably never become a leading industry, it seems certain that vegetables, small fruits, and certain orchard fruits might be produced in greater quantity and of much better quality than they are at present if the fullest use were made of the possibilities of irrigation from wells. If such a use were found for all the water available, the desirability of packing in all cases where the water level in the well could thereby be materially heightened is evident.

Efficient and systematic irrigation of gardens from deep wells would involve the construction of reservoirs, either wooden tanks or excavations lined with masonry or sod. The methods of irrigation can not, however, be dealt with in this paper. Those interested in the subject will do well to refer to Mr. Newell's recent work on irrigation,[a] where all the branches of that important art are treated fully.

CONCLUSION.

This report may be closed appropriately with a brief recapitulation of the more important points developed in the preceding pages on the deep wells of east-central Washington.

In the wheat lands the records of numerous wells demonstrate that abundant water of good quality can be obtained from porous layers in the basalt series at depths varying from 40 to 670 feet. In general, the average depth at which a good supply is reached increases gradually toward the south.

The water generally rises in these wells to a greater or less extent, which proves that the deep waters beneath the wheat lands are under pressure, and that they are, therefore, in the broad sense of the term, artesian. Despite these encouraging manifestations, however, no instance is known in which an attempt has been made to measure the effective head of the artesian streams, nor has any well in the region been cased to prevent leakage through porous beds above the confining stratum of compact basalt. There is good reason to believe that

[a] Newell, F. H., Irrigation in the United States, New York, 1902.

there are wells in the wheat lands in which the water fails to reach the top solely on account of leakage through loose surface material.

It is strongly urged, therefore, that the more favorably situated wells be tested thoroughly in order that definite information may be obtained regarding artesian pressures. Directions for making such tests have been given in the appropriate place. All wells which then prove capable of giving a surface flow should be efficiently cased.

It is thought advisable not only to case any wells that will give a surface flow, but to pack the bottom of the pipe in many other wells in which the water surface could, by that means, be raised materially. Such a procedure would be economical where, on the one hand, a gasoline or steam pumping engine is used and the running expenses for fuel, etc., are considerable; or where, on the other hand, a windmill is used and the running expenses are insignificant but it is desired to augment the supply by this means if use can be found for all the water that can be obtained. It is suggested that irrigation of gardens and orchards from deep wells would afford a profitable means of utilizing most of the water that can be developed in excess of the requirements of stock and the household.

There seems to be a fairly good chance of obtaining artesian fountains in the vicinity of Lind and of Parnell and in the coulees west of the Lind-Ritzville district, but the artesian pressures are probably insufficient to raise water to the general plateau levels of the wheat lands.

In the arid range land just east of the Columbia water could be found at comparatively moderate depths, but conditions do not favor the hope of obtaining artesian flows. A number of stock wells could probably be sunk in this region to advantage, and if located at points far from any of the natural drinking places might render available some areas now largely neglected by the stock because of their distance from water. The excessively grazed stretches near the streams and springs might then have an opportunity to recuperate if the number of animals on the range could be kept within a reasonable limit. The ruin of this range seems imminent, however, unless those who have grazing interests there adopt a conservative policy. The wastefulness and shortsightedness of overstocking has too often been demonstrated by experience and only realized when the evil was past remedy.

That there would be better chances of obtaining artesian flows on the Columbia Plains by very deep borings than from some of the moderately deep wells now existing is doubtful. Deep experimental borings in the basalt are to be regarded in the present condition of our knowledge as involving considerable financial risk. The searcher for artesian water should make careful and exhaustive tests of the upper water horizons before he sinks capital in a deep boring.

The writer believes that wells sunk in the lower portions of Kittitas Valley to the base of the Ellensburg series and properly cased would yield artesian flows. If, however, a properly conducted experiment resulted in failure to obtain a flow from the Ellensburg series, the advisability of continuing the boring into the basalt underneath would be doubtful. Granting, however, that the chances of obtaining surface flows are good, the wisdom of prospecting for artesian water in Kittitas Valley must depend upon the answer to the question whether, if an artesian supply were obtained, it could be used economically.

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Correspondence should be addressed to

The Director,
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DEPARTMENT OF THE INTERIOR

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

INDEX

TO THE

HYDROGRAPHIC PROGRESS REPORTS

OF THE

UNITED STATES GEOLOGICAL SURVEY

1888 to 1903

BY

JOHN C. HOYT AND B. D. WOOD

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LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
Washington, D. C., January 16, 1905.

SIR: I transmit herewith the manuscript for an index to the hydrographic progress reports of the United States Geological Survey issued during 1888 to 1903, inclusive. This manuscript has been prepared by John C. Hoyt and B. D. Wood, and I request that it be published as a water-supply and irrigation paper.

Very respectfully,

F. H. NEWELL,
Chief Engineer.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

INDEX TO THE HYDROGRAPHIC PROGRESS REPORTS OF THE UNITED STATES GEOLOGICAL SURVEY, 1888 TO 1903.

By John C. Hoyt and B. D. Wood.

INTRODUCTION.

A systematic study of the surface waters of the United States was started by the hydrographic branch of the United States Geological Survey in 1888. A large part of this work has consisted of the measurement of the volume of flow and of the study of conditions affecting it. For each calendar year there has been prepared a Report of Progress of Stream Measurements, embodying the data collected during that year, which has been published either as a part of the annual report of the Director, as a bulletin, or as a water-supply and irrigation paper, as shown by the following list:

1888. Tenth Annual Report, Part II.
1889. Eleventh Annual Report, Part II.
1890. Twelfth Annual Report, Part II.
1891. Thirteenth Annual Report, Part III.
1892. Fourteenth Annual Report, Part II.
1893. Bulletin No. 131.
1894. Bulletin No. 131, and Sixteenth Annual Report, Part II.
1895. Bulletin No. 140, and Seventeenth Annual Report, Part II.
1896. Water-Supply Paper No. 11; Eighteenth Annual Report, Part IV.
1897. Water-Supply Papers Nos. 15 and 16; Nineteenth Annual Report, Part IV.
1898. Water-Supply Papers Nos. 27 and 28; Twentieth Annual Report, Part IV.
1899. Water-Supply Papers Nos. 35 to 39, inclusive; Twenty-first Annual Report, Part IV.
1900. Water-Supply Papers Nos. 47 to 52, inclusive; Twenty-second Annual Report, Part IV.
1901. Water-Supply Papers Nos. 65, 66, and 75.
1902. Water-Supply Papers Nos. 82 to 85, inclusive.
1903. Water-Supply Papers Nos. 97 to 100, inclusive.

As the hydrographic work in most localities has continued during several years, the results of the investigations at any one point are scattered through a number of publications, and the only guide to these data has been the individual indexes. With the growing interest in the commercial development of the hydrographic resources of

the country the demand for these data collected by the Geological Survey has rapidly increased, and in order to aid those wishing to use them this index has been prepared. In its preparation each publication of the foregoing list was carefully reviewed, the data were classified, and entries were made under both names of rivers and names of places.

As the work of the hydrographic branch increased it became necessary to publish a special series of reports to contain the data collected, and the series of Water-Supply and Irrigation Papers was therefore begun. The papers of this series have been classified as follows:

(I) Irrigation.
(J) Water storage.
(K) Pumping water.
(L) Quality of water.
(M) General hydrographic investigations.
(N) Water powers.
(O) Underground waters.
(P) Hydrographic progress reports.

A certain number of these publications, as of all publications of the Geological Survey, are published for free distribution by the Survey, and a certain number are deposited with the Superintendent of Public Documents, Washington, D. C., from whom they may be purchased at a nominal price. Other copies are allotted to the various Congressmen for distribution. As the edition of most of the publications is limited, the supply is soon exhausted. Those who are interested, however, may be able to find copies on file in the public libraries of most of the large cities, or in the libraries of engineering societies.

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